Innovative Integration

... real time solutions!

X3-Servo User's Manual

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The X3-Servo User's Manual was prepared by the technical staff of Innovative Integration on July 7, 2009.

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VSS \ Distributions \ Servo \ Documentation \ Manual \ ServoMaster.odm

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Rev 1.1

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Introduction

Real Time Solutions!

Thank you for choosing Innovative Integration, we appreciate your business! Since 1988, Innovative Integration has grown to become one of the world's leading suppliers of DSP and data acquisition solutions. Innovative offers a product portfolio unrivaled in its depth and its range of performance and I/O capabilities .

Whether you are seeking a simple DSP development platform or a complex, multiprocessor, multichannel data acquisition system, Innovative Integration has the solution. To enhance your productivity, our hardware products are supported by comprehensive software libraries and device drivers providing optimal performance and maximum portability.

Innovative Integration's products employ the latest digital signal processor technology thereby providing you the competitive edge so critical in today's global markets. Using our powerful data acquisition and DSP products allows you to incorporate leading-edge technology into your system without the risk normally associated with advanced product development. Your efforts are channeled into the area you know best ... your application.

Vocabulary

What is X3-Servo?

The X3 module Family are XMC (VITA 42.3) modules with a variety of IO capabilities and a PCI Express interface. Each modules has a Spartan 3 application FPGA, buffer memory and clocking features to support the IO functions. Two SRAMs are used, one each for buffer memory and application memory. Then XMC has a 32/66 PCI interface to a single lane PCIe bridge chip DIO using P16 connection to the baseboard.

For sample rate generation, the X3-Servo has a precision, low noise PLL or external clocks. Trigger modes including software, framed and external triggering provide precise control over sample acquisition and synchronization with other devices. Timestamped alerts also provide the ability to monitor the acquisition process and correlate system events to the data.

Data acquisition control, signal processing, buffering, and system interface functions are implemented in a Xilinx Spartan3 FPGA, 1M gate device. Two 512Kx32 memory devices are used for data buffering and FPGA computing memory.

The logic can be fully customized using VHDL and MATLAB using the FrameWork Logic toolset. The MATLAB BSP supports real-time hardware-in-the-loop development using the graphical, block diagram Simulink environment with Xilinx System Generator.

The PCI Express interface supports continuous data rates up to 180 MB/ s between the module and the host. A flexible data packet system implemented over the PCIe interface provides both high data rates to the host that is readily expandable for custom applications.

What is Malibu?

Malibu is the Innovative Integration-authored component suite, which combines with the Borland, Microsoft or GNU C++ compilers and IDEs to support programming of Innovative hardware products under Windows and Linux. Malibu supports both high-speed data streaming plus asynchronous mailbox communications between the DSP and the Host PC, plus a wealth of Host functions to visualize and post-process data received from or to be sent to the target DSP.

What is C++ Builder?

C++ Builder is a general-purpose code-authoring environment suitable for development of Windows applications of any type. Armada extends the Builder IDE through the addition of functional blocks (VCL components) specifically tailored to perform real-time data streaming functions.

What is Microsoft MSVC?

MSVC is a general-purpose code-authoring environment suitable for development of Windows applications of any type. Armada extends the MSVC IDE through the addition of dynamically created MSVC-compatible C++ classes specifically tailored to perform real-time data streaming functions.

What kinds of applications are possible with Innovative Integration hardware?
Data acquisition, data logging, stimulus-response and signal processing jobs are easily solved with Innovative Integration baseboards using the Malibu software. There are a wide selection of peripheral devices available in the Matador DSP product family, for all types of signals from DC to RF frequency applications, video or audio processing. Additionally, multiple Innovative Integration baseboards can be used for a large channel or mixed requirement systems and data acquisition cards from Innovative can be integrated with Innovative's other DSP or data acquisition baseboards for high-performance signal processing.

Why do I need to use Malibu with my Baseboard?
One of the biggest issues in using the personal computer for data collection, control, and communications applications is the relatively poor real-time performance associated with the system. Despite the high computational power of the PC, it cannot reliably respond to real-time events at rates much faster than a few hundred hertz. The PC is really best at processing data, not collecting it. In fact, most modern operating systems like Windows are simply not focused on real-time performance, but rather on ease of use and convenience. Word processing and spreadsheets are simply not high-performance real-time tasks.

The solution to this problem is to provide specialized hardware assistance responsible solely for real- time tasks. Much the same as a dedicated video subsystem is required for adequate display performance, dedicated hardware for real-time data collection and signal processing is needed. This is precisely the focus of our baseboards – a high performance, state-of-the-art, dedicated digital signal processor coupled with real-time data I/O capable of flowing data via a 64-bit PCI bus interface.

The hardware is really only half the story. The other half is the Malibu software tool set which uses state of the art software techniques to bring our baseboards to life in the Windows environment. These software tools allow you to create applications for your baseboard that encompass the whole job - from high speed data acquisition, to the user interface.

Finding detailed information on Malibu
Information on Malibu is available in a variety of forms:

- Data Sheet (http://www.innovative-dsp.com/products/malibu.htm)
- On-line Help
- Innovative Integration Technical Support
- Innovative Integration Web Site (www.innovative-dsp.com)

Online Help

Help for Malibu is provided in a single file, Malibu.chm which is installed in the Innovative\Documentation folder during the default installation. It provides detailed information about the components contained in Malibu - their Properties, Methods, Events, and usage examples. An equivalent version of this help file in HTML help format is also available online at http://www.innovative-dsp.com/support/onlinehelp/Malibu.

Innovative Integration Technical Support

Innovative includes a variety of technical support facilities as part of the Malibu toolset. Telephone hotline supported is available via

Hotline (805) 578-4260 8:00AM-5:00 PM PST.

Alternately, you may e-mail your technical questions at any time to:

techsprt@innovative-dsp.com.

Also, feel free to register and browse our product forums at http://forum.iidsp.com/, which are an excellent source of FAQs and information submitted by Innovative employees and customers.

Innovative Integration Web Site

Additional information on Innovative Integration hardware and the Malibu Toolset is available via the Innovative Integration website at www.innovative-dsp.com

Typographic Conventions

This manual uses the typefaces described below to indicate special text.

Typeface	Meaning
`Source Listing`	Text in this style represents text as it appears onscreen or in code. It also represents anything you must type.
Boldface	Text in this style is used to strongly emphasize certain words.
Emphasis	Text in this style is used to emphasize certain words, such as new terms.
Cpp Variable	Text in this style represents C++ variables
Cpp Symbol	Text in this style represents C++ identifiers, such as class, function, or type names.
KEYCAPS	Text in this style indicates a key on your keyboard. For example, “Press ESC to exit a menu”.
Menu Command	Text in this style represents menu commands. For example “Click View | Tools | Customize”

Windows Installation

This chapter describes the software and hardware installation procedure for the Windows platform (WindowsXP and Vista).

> **<u>Do *NOT*</u>** install the hardware card into your system at this time. This will follow the software installation.

Host Hardware Requirements

The software development tools require an IBM or 100% compatible Pentium IV - class or higher machine for proper operation. An Intel-brand processor CPU is *strongly recommended*, since AMD and other “clone” processors are not guaranteed to be compatible with the Intel MMX and SIMD instruction-set extensions which the Armada and Malibu Host libraries utilize extensively to improve processing performance within a number of its components. The host system must have at least 128 Mbytes of memory (256MB recommended), 100 Mbytes available hard disk space, and a DVD-ROM drive. Windows2000 or WindowsXP (referred to herein simply as *Windows*) is required to run the developer’s package software, and are the target operating systems for which host software development is supported.

Software Installation

The development package installation program will guide you through the installation process.

> **Note:** Before installing the host development libraries (VCL components or MFC classes), you must have Microsoft MSVC Studio (version 9 or later) and/or Codegear RAD Studio C++ (version 11) installed on your system, depending on which of these IDEs you plan to use for Host development. If you are planning on using these environments, it is imperative that they are tested and known-operational before proceeding with the library installation. If these items are not installed prior to running the Innovative Integration install, the installation program will not permit installation of the associated development libraries. However, drivers and DLLs may be installed to facilitate field deployment.

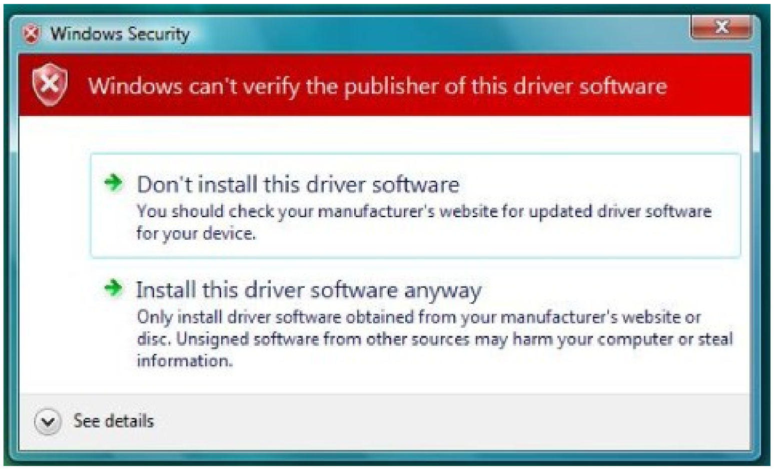
You must have **Administrator Privileges** to install and run the software/hardware onto your system, refer to the Windows documentation for details on how to get these privileges.

Starting the Installation

To begin the installation, start Windows. Shut down all running programs and disable anti-virus software. Insert the installation **DVD**. If Autostart is enabled on your system, the install program will launch. If the DVD does not Autostart, click on Start | Run... Enter the path to the **Setup.bat** program located at the root of your DVD-ROM drive (i.e. **E:\Setup.bat**) and click "OK" to launch the setup program.

SETUP.BAT detects if the OS is 64-bit or 32-bit and runs the appropriate installation for each environment. It is important that this script be run to launch an install.

When installing on a Vista OS, the dialog below may pop up. In each case, select "Install this driver software anyway" to continue.



Windows Security

Windows can't verify the publisher of this driver software

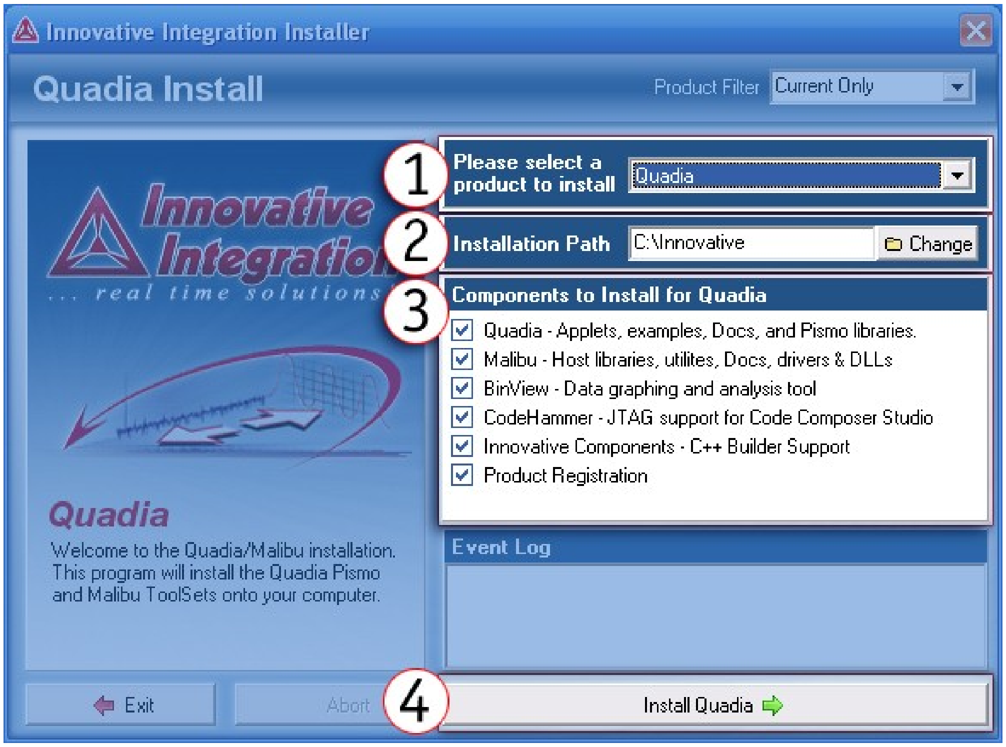
Don't install this driver software
You should check your manufacturer's website for updated driver software for your device.

Install this driver software anyway
Only install driver software obtained from your manufacturer's website or disc. Unsigned software from other sources may harm your computer or steal information.

Figure 1. Vista Verification Dialog

The Installer Program

After launching Setup, you will be presented with the following screen.



Product Filter: Current Only

Please select a product to install: Quadia

Installation Path: C:\Innovative

Components to Install for Quadia

- ☑ Quadia - Applets, examples, Docs, and Pismo libraries.
- ☑ Malibu - Host libraries, utilites, Docs, drivers & DLLs
- ☑ BinView - Data graphing and analysis tool
- ☑ CodeHammer - JTAG support for Code Composer Studio
- ☑ Innovative Components - C++ Builder Support
- ☑ Product Registration

Quadia

Welcome to the Quadia/Malibu installation. This program will install the Quadia Pismo and Malibu ToolSets onto your computer.

Figure 2. Innovative Install Program

Using this interface, specify which product to install, and where on your system to install it.

1) Select the appropriate product from the Product Menu.

2) Specify the path where the development package files are to be installed. You may type a path or click "**Change**" to browse for, or create, a directory. If left unchanged, the install will use the default location of "C:\Innovative".

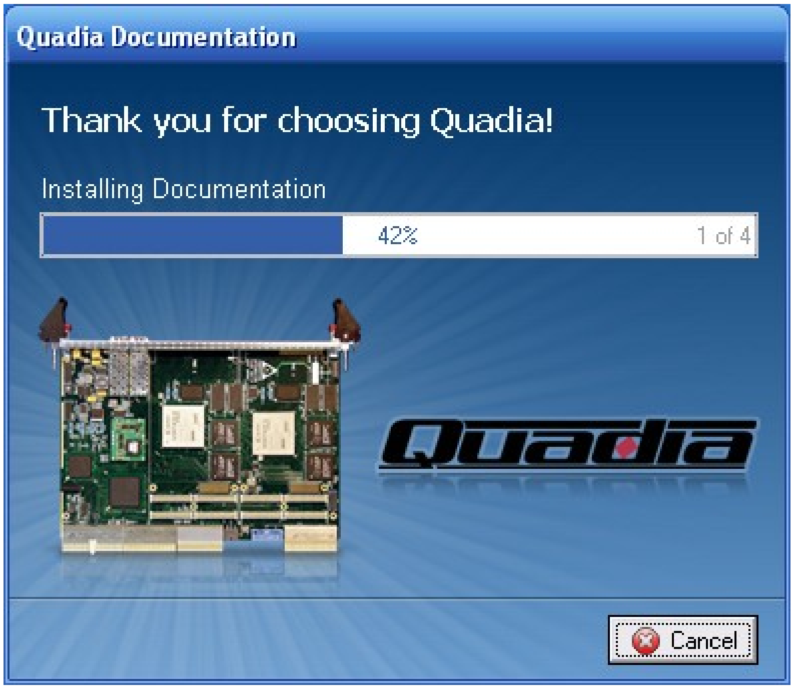
3) Typically, most users will perform a "Full Install" by leaving all items in the "**Components to Install**" box checked. If you do not wish to install a particular item, simply uncheck it. The Installer will alert you and automatically uncheck any item that requires a development environment that is not detected on your system.

4) Click the Install button to begin the installation.

Note: The default "Product Filter" setting for the installer interface is "Current Only" as indicated by the combo box located at the top right of the screen. If the install that you require does not appear in the "Product Selection Box" (1), Change the "Product Filter" to "Current plus Legacy".

Each item of the checklist in the screen shown above, has a sub-install associated with it and will open a sub-install screen if checked. For example, the first sub-install for "Quadia - Applets, Examples, Docs, and Pismo libraries" is shown below.

The installation will display a progress window, similar to the one shown below, for each item checked.



Quadia Documentation

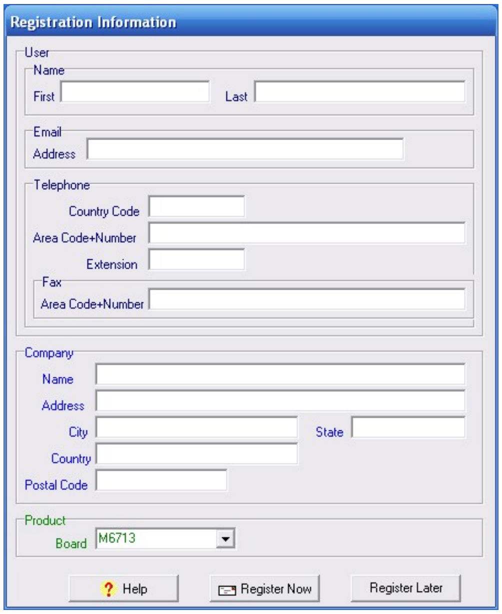
Thank you for choosing Quadia!

Installing Documentation

Figure 3. Progress is shown for each section.

Tools Registration

At the end of the installation process you will be prompted to register. If you decide that you would like to register at a later time, click “Register Later”.



Board M6713

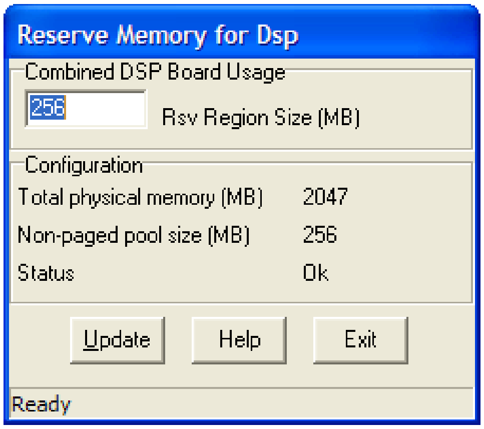
When you are ready to register, click Start | All Programs | Innovative | <Board Name> | Applets. Open the New User folder and launch **NewUser.exe** to start the registration application. The registration form to the left will be displayed.

Before beginning DSP and Host software development, you must register your installation with Innovative Integration. Technical support will not be provided until registration is successfully completed. Additionally, some development applets will not operate until unlocked with a passcode provided during the registration process.

It is recommend that you completely fill out this form and return it to Innovative Integration, via email or fax. Upon receipt, Innovative Integration will provide access codes to enable technical support and unrestricted access to applets.

Figure 4. ToolSet registration form

Bus Master Memory Reservation Applet.



256 Rsv Region Size (MB)

Total physical memory (MB) 2047

Non-paged pool size (MB) 256

Status Ok

Ready

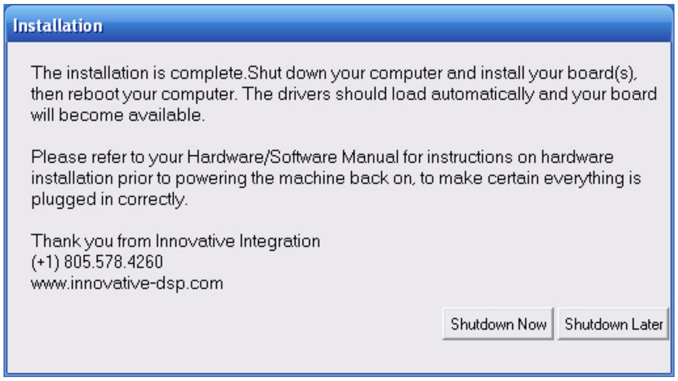
Figure 5. BusMaster configuration

At the conclusion of the installation process, **ReserveMem.exe** will run (except for SBC products). This will allow you to set the memory size needed for the busmastering to occur properly. This applet may be run from the start menu later if you need to change the parameters.

For optimum performance each Matador Family Baseboard requires 2 MB of memory to be reserved for its use. To reserve this memory, the registry must be updated using the ReserveMem applet. Simply select the **Number of Baseboards** you have on your system, click **Update** and the applet will update the registry for you. If at any time you change the number of boards in your system, then you must invoke this applet found in Start | All Programs | Innovative | <target board> | Applets | Reserve Memory.

After updating the system exit the applet by clicking the **exit** button to resume the installation process.

At the end of the install process, the following screen will appear.



The installation is complete.Shut down your computer and install your board(s), then reboot your computer. The drivers should load automatically and your board will become available.

Please refer to your Hardware/Software Manual for instructions on hardware installation prior to powering the machine back on, to make certain everything is plugged in correctly.

Thank you from Innovative Integration
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www.innovative-dsp.com

Figure 6. Installation complete

Click the “Shutdown Now” button to shut down your computer. Once the shutdown process is complete unplug the system power cord from the power outlet and proceed to the next section, “Hardware Installation.”

Hardware Installation

Now that the software components of the Development Package have been installed the next step is to configure and install your hardware. Detailed instructions on board installation are given in the Hardware Installation chapter, following this chapter.

> **IMPORTANT:** Many of our high speed cards, especially the PMC and XMC Families, require forced air from a fan on the board for cooling. Operating the board without proper airflow may lead to improper functioning, poor results, and even permanent physical damage to the board. These boards also have temperature monitoring features to check the operating temperature. The board may also be designed to intentionally fail on over-temperature to avoid permanent damage. See the specific hardware information for airflow requirements.

After Power-up

After completing the installation, boot your system into Windows.

Innovative Integration boards are plug and play compliant, allowing Windows to detect them and auto-configure at start-up. Under rare circumstances, Windows will fail to auto-install the device-drivers for the JTAG and baseboards. If this happens, please refer to the “TroubleShooting” section.

Installation on Linux

This chapter contains instruction on the installation of the baseboard software for Linux operating systems.

Software installation on Linux is performed by loading a number of **packages**. A Package is a special kind of archive file that contains not only the files that are to be installed, but also installation scripts and dependency information to allow a smooth fit into the system. This information allows the package to be removed, or patched. Innovative uses RPM packages in its installs.

Package File Names
A package file name such as Malibu-LinuxPeriphLib-1.1-3.i586.rpm encodes a lot of information.

Package Name		Package ID		Information Fields	
Distribution	**Subpackage**	**Version**	**Revision**	**Hardware Type**	**Extension**
Malibu-Linux	PeriphLib	1.1	3	i586	.rpm

Prerequisites for Installation

In order to properly use the baseboard example programs and to develop software using the baseboard, some packages need to be installed before the actual baseboard package.

The Redistribution Package Group - MalibuRed

This set of packages contain the libraries and drivers needed to run a program using Malibu. This group is called “MalibuRed” because it contains the packages needed to allow running Malibu based programs on a target, non-development machine. (Red is short for 'redistributable').

MalibuRed Packages	Description
WinDriver-9.2-1.i586.rpm	Installs WinDriver 9.2 release.
MalibuLinux-Red-**[ver]**-**[rel]**.i586.rpm	Installs Baseboard Driver Kernel Plugin.
intel-ipp_rti-5.3p.x32.rpm	Installs Intel IPP library redistributable files.

The installation CD, or the web site contains a file called **LinuxNotes.pdf** giving instructions on how to load these packages and how to install the drivers onto your Linux machine. This file is also loaded onto the target machine by the the Malibu-LinuxRed RPM. These procedures need to be completed for every target machine.

Malibu

To develop software for a baseboard the Malibu packages also must be installed.

Malibu Packages	Description
Malibu-LinuxPeriphLib-**[ver]**-**[rel]**.i586.rpm	Installs Malibu Source, Libraries and Examples.

Other Software

Our examples use the DialogBlocks designer software and wxWidgets GUI library package for user interface code. If you wish to rebuild the example programs you will have to install this software as well.

Package	Company	URL
wxWidgets	wxWidgets	http://www.wxwidgets.org
DialogBlocks	Anthemion	http://www.anthemion.co.uk.org/dialogblocks

Baseboard Package Installation Procedure

Each baseboard installation for Linux consists of one or more package files containing self-extracting packages of compressed files, as listed in the table below. Note that package version codes may vary from those listed in the table.

Each of these packages automatically extract files into the `/usr/Innovative` folder, herein referred to as the *Innovative root folder* in the text that follows. For example, the X5-400 RPM extracts into `/usr/Innovative/X5-400-[ver]`. A symbolic link named `X5-400` is then created pointing to the version directory to allow a single name to apply to any version that is in use.

Board Packages

Baseboard	Packages	Description
X5-400M	Malibu-LinuxPeriphLib-[**ver**]-[**rel**].i586.rpm	Board files and examples.
X5-210M	X5-210M-LinuxPeriphLib-**[ver]-[rel]**.i586.rpm	Board files and examples.
X3-10M	X3-10M-LinuxPeriphLib-**[ver]-[rel]**.i586.rpm	Board files and examples.
X3-25M	X3-25M-LinuxPeriphLib-**[ver]-[rel]**.i586.rpm	Board files and examples.
X3-A4D4	X3-A4D4-LinuxPeriphLib-**[ver]-[rel]**.i586.rpm	Board files and examples.
X3-SD	X3-SD-LinuxPeriphLib-**[ver]-[rel]**.i586.rpm	Board files and examples.
X3-SDF	X3-SDF-LinuxPeriphLib-**[ver]-[rel]**.i586.rpm	Board files and examples.
X3-Servo	X3-Servo-LinuxPeriphLib-**[ver]-[rel]**.i586.rpm	Board files and examples.
SBC-ComEx	Sbc-ComEx-LinuxPeriphLib-**[ver]-[rel]**.i586.rpm	Board files and examples.

Unpacking the Package

As root, type:

```
rpm -i -h X5-400-LinuxPeriphLib-1.1-4.i586.rpm
```

This extracts the X5-400 board files into the Innovative root directory. Use the package for the particular board you are installing.

Creating Symbolic Links

The example programs assume that the user has created symbolic links for the installed board packages. A script file is provided to simplify this operation by the Malibu Red package. In the MalibuRed/KerPlug directory, there is a script called quicklink.

```
quicklink X5-400 1.1
```

These commands will create a symbolic link `X5-400` pointing to `X5-400-1.1`.

This script can be moved to the user's `bin` directory to allow it to be run from any directory.

Completing the Board Install

The normal board install is complete with the installation of the files. The board driver install is already complete with the loading of the Malibu Red package. If there are any board-specific steps they will be listed at the end of this chapter.

Linux Directory Structure

When a board package is installed, its files are placed under the `/usr/Innovative` folder. The base directory is named after the board with a version number attached -- for example, the version 2.0 X5-400 RPM extracts into `/usr/Innovative/X5-400-2.0.`

This allows multiple version of installs to coexist by using a symbolic link to point to a particular version. Changing the symbolic link changes with version will be used.

Under the main directory there are a number of subdirectories.

Applets
The applets subdirectory contains small application programs that aid in the use of the board. For example, there is a Finder program that allows the user to flash an LED on the board to determine which board is associated with a target number. See the Applets chapter for a fuller description of the applets for a board.

Documentation
This directory contains any documentation files for the project. Open the index.html file in the directory with a web browser to see the available files and a description of the contents.

Examples
This directory and its subdirectories contain the projects, source and example programs for the board.

Hardware
This directory contains files associated with programming the board Logic and any logic images provided.

About the X3 XMC Modules

In this chapter, we will discuss the common features of the X3 module family. Specifics on each module are covered in later chapters.

X3 XMC Architecture

The X3 XMC modules share a common architecture as well as many features such as the PCI Express interface, data buffering features, the Application Logic, and other system integration features. This allows the X3 XMC modules to utilize common software and logic firmware, while providing unique analog and digital features.

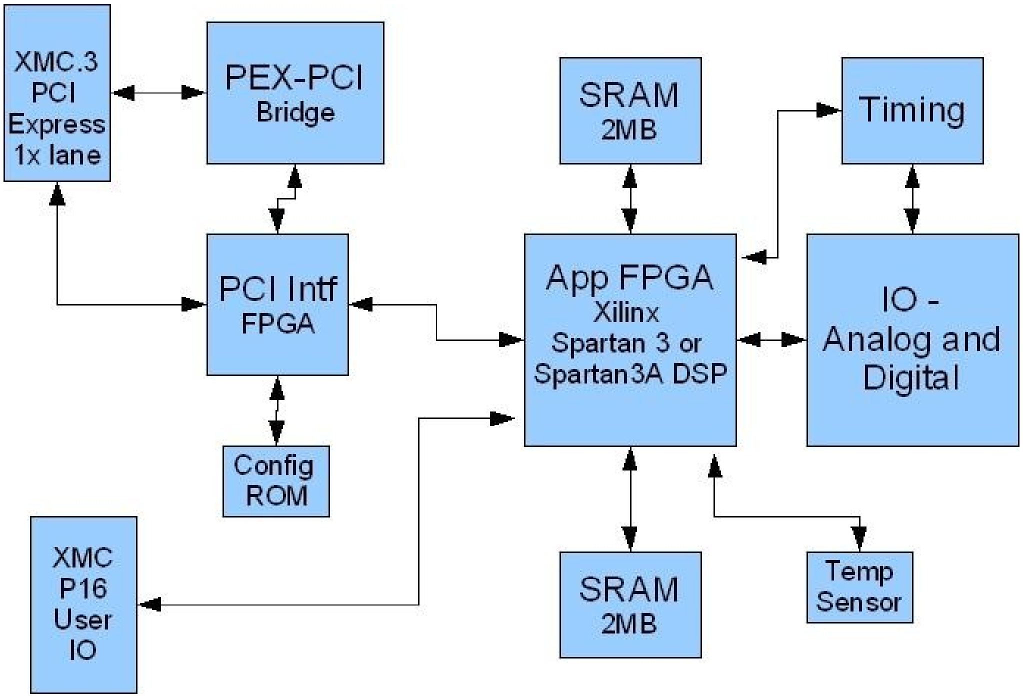


Figure 7. X3 XMC Family Block Diagram

The X3 XMCs have a variety of analog and digital IO front ends suited to many applications.

Table 1. X3 XMC Family

X3 XMC	Features	FPGA	Applications
X3-SD	16 channels of 24-bit, 216 ksps A/D, >100 dB	Xilinx Spartan3 1M (2M option)	Vibration measurement, acoustics, wide dynamic range applications
X3-SDF	4 channels of variable resolution/speed A/D up to 24-bit, 5 MSPS or 16-bit 20 MSPS, >100 dB below 2.5 MSPS	Xilinx Spartan3 1M (2M option)	Vibration measurement, acoustics, wide dynamic range applications
X3-25M	Two channels of 25 MSPS, 16-bit A/D and two channels of 16-bit, 50 MSPS DAC, 16-bits front panel DIO	Xilinx Spartan3A DSP 1.8M	Ultrasound, pulse digitizing, waveform generation and stimulus-response
X3-A4D4	4 channels of 16-bit, 4 MSPS A/D and 4 channels 16-bit 2 MHz DAC with low latency, 8-bits front panel DIO	Xilinx Spartan3A DSP 1.8M	Servo controls, process instrumentation
X3-Servo	12 channels 16-bit, 250 ksps A/D and 12 channels 16-bit 250 ksps DAC, low latency, 16-bits front panel DIO	Xilinx Spartan3A DSP 1.8M (3.4M option)	Electromechanical controls, process instrumentation
X3-DIO	64 bits/32 pairs digital IO to FPGA, LVCMOS or LVDS, with streaming, playback and capture features	Xilinx Spartan3A DSP 1.8M (3.4M option)	Test pattern generation, remote IO interfaces, digital controls
X3-10M	8 channels of 16-bit, 25 MSPS A/D with programmable gain and instrumentation front end; Xilinx Spartan3A DSP FPGA	Xilinx Spartan3A DSP 1.8M	Measurement for high speed vibration, ultrasound fault detection systems, neurophysical applications

The X3 XMCs feature a Xilinx Spartan3 or Spartan3A DSP FPGA core for signal processing and control. In addition to the features in the Spartan3/3A logic such as embedded multipliers and memory blocks, the FPGA computing core has two local SRAMs for data buffering and computing memory.

There are also a number of support peripherals for IO control and system integration. Each XMC may have additional application-specific support peripherals.

Table 2. X3 XMC Family Peripherals

Peripheral	Features
XMC.3 PCI Express interface	The XMC.3 host interface Integrates with PCI Express systems using one lane operating at 2.5 Gbps that provides up to 180 MB/s sustained data rates. This interface complies with VITA standard 42.3 which specifies PCI Express interface for the XMC module format. The Velocia packet system provides fast and flexible communications with the host using a credit-based flow control supporting packet transfers with the host. A secondary command channel provides independent interface for control and status outside of the data channel that is extensible to custom applications.
XMC P16	Provides digital IO or a private link to host cards capable of >200 MB/s sustained operation.

Peripheral	Features
Timing and triggering	Flexible clocking and synchronization features for IO
Data buffering and Computational Memory	Two 2MB SRAM devices are used provide data buffering, processor memory and computation memory for the Application FPGA
Alert Log	Monitors system events and error conditions to help manage the data acqusiton process
Temperature Sensor	Monitors the module temperature and provides thermal protection for the module

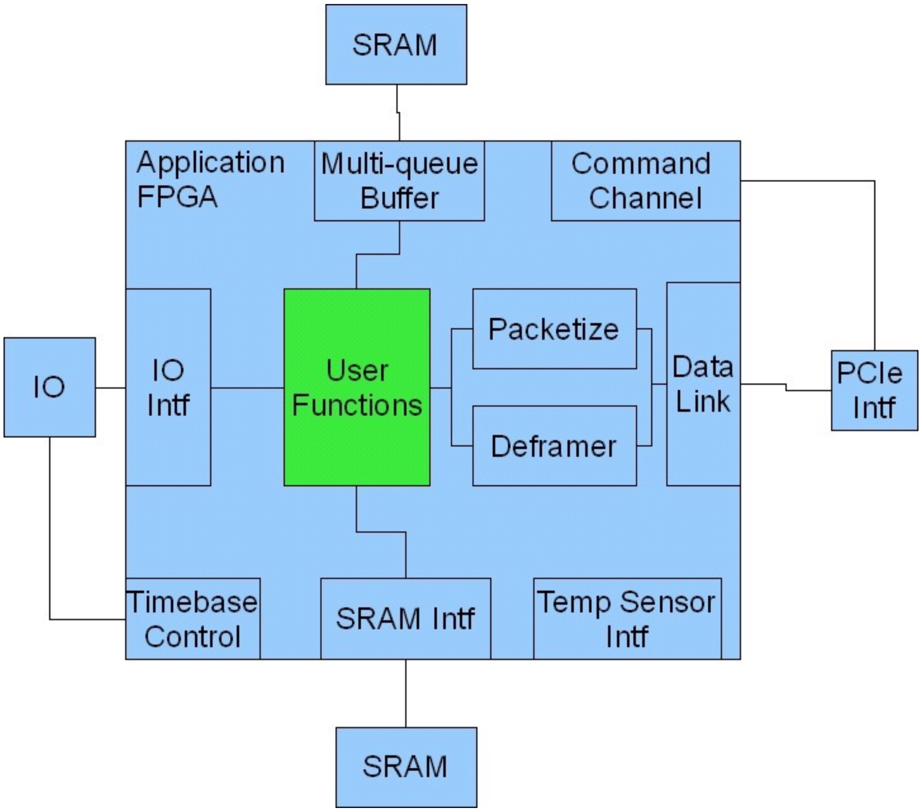
X3 Computing Core

The X3 XMC module family has an FPGA-based computing core that controls the data acquisition process, providing data buffing and host communications. The computing core consists of a Xilinx Spartan3 or 3A DSP FPGA and two banks of 2MB SRAM memory. The FPGA uses the memories for data buffering and computational workspace.

Table 3. X3 Computing Core Devices

Feature	X3 Module	Device	Part Number
Application Logic FPGA	SD, SDF	Xilinx Spartan 3 1M	XC3S1000-4FGG456C
	10M, Servo, 25M, DIO	Xilinx Spartan 3A DSP 1.8M	XC3SD1800-4FGG676C
Buffer Memory SRAM	SD, SDF	Synchronous Burst ZBT SRAM	1Mx16, 100 MHz
	10M, Servo, 25M, DIO		512Kx32, 133 MHz
Computational Memory SRAM	SD, SDF	Synchronous Burst ZBT SRAM	1Mx16, 100 MHz
	10M, Servo, 25M, DIO		512Kx32, 133 MHz

The main focus of the module is the X3's computing core which connects the IO, peripherals, host communications and support features. Each IO device directly connects to the application FPGA on the X3 module, providing tight coupling for high performance. (Real-time IO). The FPGA logic implements an interface to each device that connects them to the controls and data communications features on the module. Support features, such as sample triggering and data analysis, are implemented in the logic to provide precise real-time control over the data acquisition process.



X3 Computing Core Block Diagram

The X3 module architecture is really defined by the features in the logic that connect the IO devices to the Velocia packet system. For data from IO devices such as A/Ds, the data flows from the IO interface and is then enqueued in the multi-queue buffer. The packetizer then creates data packets from the data stream that are moved across the data link to the PCIe interface. Packets to output devices travel in the opposite direction – from the link to the deframer and into the multi-queue data buffer. The output IO, such as a DAC, then consumes the data from the queue as required. The Alert Log monitors error conditions and important events for management of the data acquisition process.

The host interacts with the X3 computing core using the packet system for high speed data and over the command channel. The packet system is the main data channel to the card and delivers the high performance, real-time data capability of moving data to and from the module. Since it uses an efficient DMA system, it is very efficient at moving data which leaves the host system unburdened by the data flow. The command channel provides the PCIe host direct access to the computing core logic for status, control and initialization. Since it is outside the packet system, it is less complex to use and provides unimpeded access to the logic.

The application FPGA image is loaded by the host computer as part of the module initialization. The image is loaded over the SelectMAP interface to the FPGA, which is a byte-wide configuration port on the FPGA, from the host PCI Express interface. The configuration port for the FPGA is independent of the packet interface to the host and does not involve the use of the Velocia packet system. The image can be loaded at any time over the SelectMAP interface allowing dynamic configuration of the FPGA for advanced applications.

Note: There is no on-card storage for this image and it must be loaded each time the host computer is powered down or reset.

Adding New Features to the FPGA

The functionality of the computing core can be modified using the FrameWork Logic tools for the X3 module family. The tools support development in either VHDL or MATLAB. Signal processing, data analysis and unique functions can be added to the X3 modules to suit application-specific requirements. See the *X3 FrameWork Logic User Guide* for further information.

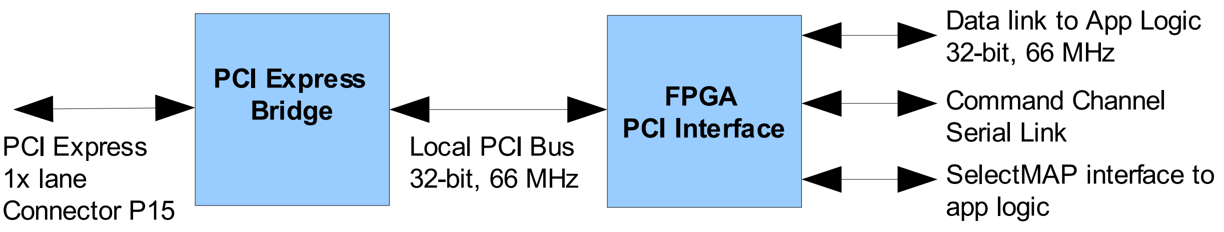
X3 PCI Express Interface

The X3 module family has a PCI Express interface that provides a lane, 2.5 Gbps full duplex link to the host computer. The interface is compatible with industry standard PCI Express systems and may be used in a variety of host computers. The following standards govern the PCI Express interface on the X3 XMC modules.

Table 4. PCI Express Standards Compliance

Standard	Describes	Standards Group
PCI Express 1.0a	PCI Express electrical and protocol standards. 2.5 Gbps data rate.	PCI SIG (http://www.picmg.com)
ANSI/VITA 42	XMC module mechanicals and connectors	VITA (www.vita.org)
ANSI VITA 42.3	XMC module with PCI Express Interface.	VITA (www.vita.org)

The X3 module family uses a Texas Instruments bridge chip to go from PCI Express to a local PCI bus on the module. The PCI Express bridge works with the PCI FGPA to implement the Velocia packet system for data communications and also provides the module configuration and control features.



The major interfaces to the application logic are the data link, command channel and SelectMAP interface. The data link provides a high performance channel for the application logic to communicate with the host computer while the Command Channel is a command and control interface from the host computer to the application logic. The SelectMAP interface is the application FPGA configuration port for loading the logic image.

The data link is the primary data path for the data communications between the application FPGA and host computer. When data packets are created by the application logic, such as A/D samples, or required by the application logic for output devices, such as DAC channels, the data flows over the data link as packets. The maximum transfer rate over the data link is 264 MB/s, with a 220 MB/s sustained rate. The data packets contain a Peripheral Device Number (PDN) that identifies the peripheral associated with the this data packet. In this way, the packet system is extensible to other devices that may be added to the logic. For example, an FFT analysis can be added to the logic and its result sent to the host as a new PDN for display and further analysis while maintaining other data streams from A/D channels.

Table 5. Interfaces from PCI Express to Application Logic

Application Logic Interface	Max Data Rate	Typical Use
Data Link	264 MB/s burst, 240 MB/s sustained	Velocia packet system interface - main path for data communications
Command Channel	5 MB/s sustained	Command, control and status
SelectMAP	5 MB/s	Application logic configuration

Data Buffering and Memory Use

There are two 2MB SBSRAM devices attached to the application FPGA that provide data buffering and computational RAM for FPGA applications.

Computational SRAM

The SRAM on the X3 family is a 2MB memory dedicated as FPGA local memory. Applications in the FPGA may use the SRAM as a local buffer memory if the data buffer is too large to fit in FPGA block RAMs, or as memory for an embedded processor in the FPGA.

The SRAM device connected to each Application FPGA is 2 MB total size, organized as 1M by 16 bits (X3-SD and X3-SDF) or 512K by 32 bits (all others). This device is a synchronous, ZBT SRAM and supports clock rates up to 100 MHz on X3-SD and X3-SDF, 133 MHz on all other modules. All SRAM control and data lines pins are directly connected to the FPGA, allowing the SRAM memory control to be customized to the application.

The Framework Logic provides a simple SRAM interface that can be readily modified for many types of applications. Detailed explanation of the interface control logic is described in the FrameWork Logic User Guide. The Framework Logic provides a simple register interface to the SBSRAM control logic that is used for test and demonstration. FPGA logic developers can easily replace the simple register interface logic to build on top of the high performance logic core when integrating the SRAM into their logic design.

MATLAB developers frequently use the SRAM as the real-time data buffer during development. Since the MATLAB Simulink tools operate over the FPGA JTAG during development at a low rate, it is necessary to use the SRAM for real-time, high speed data buffering. The MATLAB Simulink library for the X3 modules demonstrate the use of the SRAM as a data capture buffer. The SRAM captures real-time, high-speed data that can then be read out into MATLAB for analysis or display as a snapshot. This allows high-speed, real-time to be captured and brought into MATLAB Simulink over the slow (10Mb/sec) JTAG link. See the *X3 FrameWork Logic User Guide* for more details and examples.

Data Buffer SRAM

The second SRAM is provides a 2MB memory pool local to the FPGA. The Framework Logic implements a data buffer with one or more queues for the A/D and D/A streams as appropriate for the particular X3 module.

In the Framework logic, the SRAM use is demonstrated as a multiple queue FIFO memory that divides the 2 MB memory buffer into separate queues (virtual FIFOs) for input and output.. The logic component, referred to as Multi-Queue SRAM, controls the SRAM to create the FIFO queue functionality. Custom logic applications can use the Multi Queue SRAM buffer component to add additional queues for new devices.

EEPROM

A serial EEPROM on the X3 modules is used to store configuration and calibration information. The interface to the serial EEPROM is an I2C bus that is controlled by the PCI logic device. The device is an Atmel AT24C16-10SI, a 16K bit device. The I2C bus is slow and the calibration is read out of the EEPROM at initialization time by the application software and written into registers in the application logic for real-time error correction.

The EEPROM also has a write cycle limit of 100K cycles, so it should only be written to when calibration is performed or configuration information changes. Once the write cycle duration limit is exceeded, the device will not reliably store data any more.

Digital I/O

The X3 modules have a digital IO port and is accessible over P16 that provides basic bit IO. The port provides 44 bits of IO that may be used as inputs or outputs and a differential clock input. The port is configured and accesses directly from the PCI Express host. For more advance applications, digital IO port may be reconfigured in custom logic applications for a variety purposes since it provides direct connections to the applicant FPGA.

The DIO port is presented on P16. See the connectors section of this chapter the connector pin out and information about the connector.

Software Support

The digital I/O hardware is controlled by the IUsesExtendedDioPort class. Its properties:

Table 6. IUsesExtendedDioPort Class Operations

Function	Type	Description
DioPortConfig()	Property	Configures banks of bits for input or output
DioPortData()	Property	Broadside Read/Write to low-order 32-bits of DIO.
DioPortDataHigh()	Property	Broadside Read/Write to high-order 12-bits of DIO. Only

Typical use of the digital IO port involves first configuring the port using the Config() operator. This sets the byte direction and the clock mode. The port is then ready for read/write configurations to each port.

Hardware Implementation

Digital I/O port activity is controlled by the digital I/O configuration control and data register. Port direction is controlled by the configuration control register.

Bit	Function
0	DIO bits 7..0 direction control, 0=input, default
1	DIO bits 15..8 direction control, 0=input, default
2	DIO bits 23..16 direction control, 0=input, default
3	DIO bits 31..24 direction control, 0=input, default
4	DIO bits 39..32 output enable. '0' = input, default
5	DIO bits 43..40 output enable. '0' = input, default
30..6	-
31	Sample DIO inputs when DIO_EXT_CLK is true, otherwise always sample (0=sample always, default)

Figure 8. DIO Control Register (BAR1+0x14)

Port	Address
DIO_L	BAR1+0x13
DIO_H	BAR1+0x16

Figure 9. Digital IO Port Addresses

Data may be written to/read from the digital I/O port using the digital I/O port data registers. Data written to ports bits which are set for output mode will be latched and driven to the corresponding port pins, while data written to input bits will be ignored. The input DIO may be clocked externally by enabling the external digital clock bit in the appropriate configuration register. If the internal clock is used, the data is latched at the beginning of any read from the port. Data read from output bits is equal to the last latched bit values (i.e. the last data written to the port by the host).

Digital I/O port pins are pulled down to digital ground within the logic device. Consequently, the state of the DIO pins do not change as power is applied to the PC during system start-up. The pulldown resistor is about 8K ohms.

External signals connected to the digital I/O port bits or timer input pins should be limited to a voltage range between 0 and 3.3V referenced to ground on the digital I/O port connector. Exceeding these limits will cause damage to the X3 module.

Digital I/O Timing

The following diagram gives timing information for the digital I/O port when used in external readback clock mode (see above for details). This data is derived from device specifications and is not factory tested.

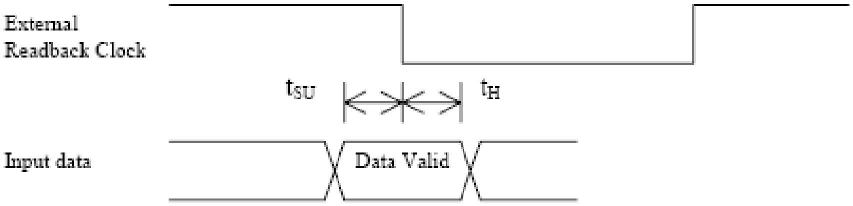


Figure 10. Digital I/O Port Timing

Table 7. Digital I/O Port Timing Parameters

Parameter	min. (ns)
tSU	5
tH	0

Digital IO Electrical Characteristics

The digital IO pins are LVTTL compatible pins driven by 3.3V logic. The DIO port connects directly to the application FPGA. The DIO input clock is LVDS, a differential input.

Warning: the DIO pins are **NOT** 5V compatible. Input voltage must not exceed 3.6V.

Parameter	Value	Notes

Input Voltage	Max = 3.6V
	Min = -0.3V
		Exceeding these will damage the application FPGA

Output Voltage	"1' > 3.0V '0' < 0.8V	For load < +/-12mA
Output Current	+/-12mA	FPGA can be reconfigured for custom designs for other drive currents.
Input Logic Thresholds	'1' >= 2VDC '0' < 0.8VDC	
Input Impedance	>1M ohm || 15 pF	Excludes cabling
Pulldown	8K ohms	Pulldown is in the logic.

Table 8. Digital IO Bits Electrical Characteristics

Parameter	Value	Notes

Input Voltage	Max = 3.6V
	Min = -0.3V
		Exceeding these will damage the application FPGA

Signaling Standard	LVDS 2.5V	EIA-644

Input common mode voltage	Min =0.30V
	Typ = 1.25V
	Max =2.20V	

Input Logic Thresholds	Min = 0.10V
	Typ = 0.30V
	Max = 0.60V
		Differential voltage Vin+ - Vin-

Termination	100 ohms	

Table 9. Digital IO Clock Input Electrical Characteristics

Notes on Digital IO Use

The digital IO on X3 family, as supported using the standard FrameWork Logic, is intended for low speed bit IO controls and status. The interface is capable of data rates exceeding 75MHz and custom logic developers can implement much higher speed and sophisticated interfaces by modifying the logic. The digital IO clock input, and LVDS signal pair, is a capable of rates exceeding 200 MHz.

Since the bit IO is connected to the command channel interface in the standard logic, this limits the effective update or read rate to about 200 kHz. The limitation on this rate is the slow speed of the command channel itself. Again, custom logic implementations can achieve much higher data rates.

The X3 FrameWork Logic user Guide details logic supporting the digital IO port and gives the pin information for customization.

Serial EEPROM Interface

X3 modules have a serial EEPROM for storing data such as board identification, calibration coefficients, and other data that needs to be stored permanently on the card. This memory is 16K bits in size. Functions for using the Serial EEPROM are included in the Malibu Toolset and example programs that allow the software application programmer to easily write and read from the memory without having to program the low-level interface.

Use the baseboard IdRom() method to obtain a reference to the internally-managed IusesPmcEeprom object, as shown below:

```
// Open the module
Innovative::X3-SD Module;
Module.Target(0);
Module.Open();

// Create a 50-32-bit-word section at offset zero in ROM user space
PmcIdromSection Section1(Module.IdRom().Rom(), PmcIdrom::waUser, 0, 50);
// Create a 50-32-bit-word section at offset 50 in ROM user space
PmcIdromSection Section2(Module.IdRom().Rom(), PmcIdrom::waUser, 50, 50);

// Write to ROM
for (int i = 0; i < 50; ++i)
       Section1.AsInt(i, i*2);
Section1.StoreToRom();

for (int i = 50; i < 100; ++i)
       Section2.AsFloat(i, static_cast<float>(i*2));
Section2.StoreToRom();

// Read from ROM
Section1.LoadFromRom();
for (int i = 0; i < 50; ++i)
       int x = Section1.AsInt(i);

Section2.LoadFromRom();
for (int i = 50; i < 100; ++i)
       float x = Section2.AsFloat(i);
```

As delivered from the factory, this EEPROM contains the calibration coefficients used for the A/D error correction.
The serial EEPROM device is an Atmel AT24C16 or equivalent.

! Caution : the serial EEPROM contains the calibration coefficients for the analog and is preprogrammed at factory test. Do not erase these coefficients or calibration will be lost.

Thermal Protection and Monitoring

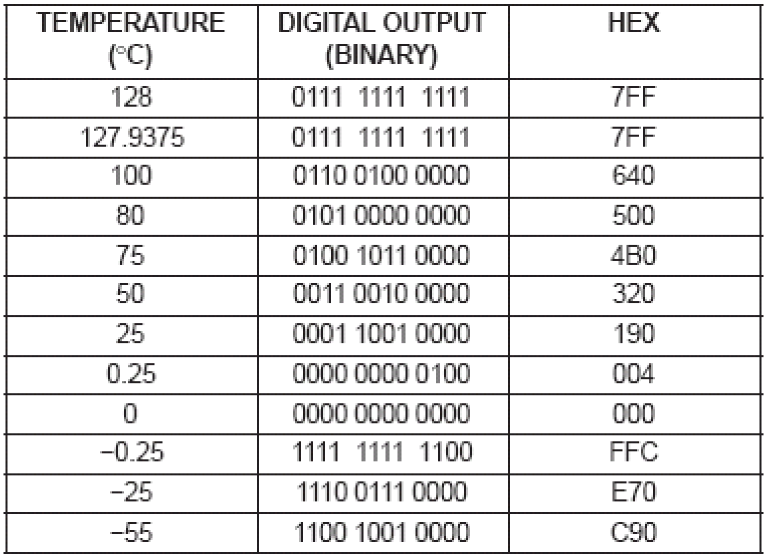
X3 modules have an on-card temperature sensor that monitors the module and protects it from thermal damage. The application software can monitor the module temperature and receive a warning if the temperature is above 70 C. If the temperature exceeds 85C, the module will shut down devices to prevent damage.

The temperature sensor is accurate to about 2 deg C with a resolution of 0.0625C. Since it is mounted near the center of the card, it indicates an average temperature, not the maximum on the module. Local hot spots may be 5 to 10 C hotter than the indicated reading.

The temperature sensor can be read by the host at address PCI BAR0 +0x3. The temperature is computed as

Temperature(C) = reading * 0.0625

where the reading is a 12-bit signed number. This table summarizes the relationship.



TEMPERATURE (°C)	DIGITAL OUTPUT (BINARY)	HEX
128	0111 1111 1111	7FF
127.9375	0111 1111 1111	7FF
100	0110 0100 0000	640
80	0101 0000 0000	500
75	0100 1011 0000	4B0
50	0011 0010 0000	320
25	0001 1001 0000	190
0.25	0000 0000 0100	004
0	0000 0000 0000	000
−0.25	1111 1111 1100	FFC
−25	1110 0111 0000	E70
−55	1100 1001 0000	C90

Table 5. Temperature Data Format

The logic component provides a programmable temperature warning (BAR0 +0x4) and failure (BAR0+0x5). The warning and fail may create alert packets when enabled. Both temperature warning and failure are latched when they occur and must be cleared by a read their respective registers.

Table 10. Temperature Alarms

Alarm Setting	Temperature (Celsius)	Set Register to ....
Warning	70	X"460"

Fail	85	X"550"

A temperature failure results in a power down signal to the analog electronics, signaling to shut down. The FPGA and host interface remain active and the module should continue to communicate unless a catastrophe has occurred. The thermal shutdown behavior of each X3 module is detailed in the specific discussion of that t module. The power down can be cleared by reading from the temperature fail register.

The temperature sensor must be present and responding for the module to operate. If the temp sensor fails, this is treated as a temperature failure. The logic continues to attempt to communicate with the temperature sensor. If multiple failure conditions are found, the logic should be reloaded.

Note that the control logic for the temperature sensor is in the application logic, so the logic must be configured to provide thermal protection. It is unlikely, except in cases of catastrophic failure that the module will overheat when the logic is not loaded since it is central to module operation.

Software support tools provide convenient access to the temperature and thermal controls. These should be used in application programming configure and monitor the temperature, as illustrated below:

```
// Open the module
Innovative::X3-SD Module;
Module.Target(0);
Module.Open();

// Create reference to thermal management object on module
const LogicTemperatureIntf & Temp(Module.Thermal());

// Read current temperature
float t = Module.LogicTemperature();

// Read/write current warning temperature
float t = Module.LogicWarningTemperature();
Module.LogicWarningTemperature(70.0);

// Read current failure temperature
float t = Module.LogicFailureTemperature();

// See if the module is in thermal shutdown
bool state = Module.Failed();
```

Thermal Failures

The X3 modules will shut down if the module temperature exceeds 85C. This means that something is seriously wrong either with the module or with the system design. Damage may occur if the module temperature exceeds this limit.

The Application LED will blink when the a temperature failure has occurred. If your software was monitoring the alert packets, you will also receive a temperature warning alert prior to failure. The module temperature can always be read by the application software so this can also provide information pointing to overheating.

The most important thing to do is to determine the root cause of the failure. The module could have failed, the system power is bad, or the environment is too harsh.

The first thing to do is inspect the module. Is anything discolored or do any ICs show evidence of damage? This may be due to device failure, system power problems, or from overheating. If damage is noticed, the module is suspect and should be sent for repair. If not, test the module outside the system in a benign environment such as on an adapter card in a desktop PC with a small fan. It should not overheat. If it does, this module is now bad.

Now consider what may have caused the failure. A bad module could be the cause, but it could have went bad due to system failure or overheating. The system power supply could cause a failure by not providing proper power to the module. This could be too little power resulting in the module failing or power glitches causing the temp sensor to drop out. Did other cards in the system fail? If so, this may indicate that a system problem must be solved.

If the module did overheat, you should review the thermal design of the system. What was the ambient temperature when failure occurred? Is the air flow adequate? Is air flow blocked to the card? Did a fan fail? If conduction cooling is being used, what is the temperature of the surrounding components? The heat must be dissipated either through conduction or convection for the module to keep from overheating.

You should also review application and be sure that you have taken advantage of any power saving features on the module. Many of the X3 modules have power saving features that allow you to turn off unused channels, reduce clock rates or stop data when the module is not in use. The chapter discussing module specifics has information on both the power consumption and the power-saving features that can be used.

LED Indicators

The X3 modules have two LEDs: one that is used for PCI Express interface and one from the application logic. Both LEDs are on the back side of the card. These LEDs are not visible from the front panel in most installations. They are used primarily for debug.

The LED from the PCI Express interface FPGA, D4, is usually used to find the target number of the module. The Finder applet blinks the LED when the target module is addressed. This allows systems with multiple modules to find out the software target number for each module. Another use for the PCI LED is to indicate that the PCI interface logic loaded. This LED should ALWAYS be on after the host computer boots. If it is not on, that means the PCI control logic did not load. The possible causes for this are: bad power, defective module, or missing PCI logic image. In any case, if this LED is off, the card will not communicate to the host system.

The second LED, D5, is from the application logic. The purpose of this LED is to indicate that the application logic has been configured and to blink when an over temperature condition occurs. Custom logic designs can use it for any purpose. When using the stock firmware, the state of user logic LED, D5 can be controlled using the `Innovative::X3-SD::Led()` property.

JTAG Scan Path

The X3 modules have a JTAG scan path for the Xilinx devices on the module. This is used for logic development tools such as Xilinx ChipScope and System Generator, and for initial programming of the PCI FPGA configuration FLASH ROM.

There are three devices in the scan chain: the Xilinx FLASH ROM, Spartan 3E 250K used for PCI control, and the Spartan 3/3A application logic. When the devices are identified in the scan chain you will see these devices in this order.

Table 11. X3 Modules FPGA JTAG Scan Path

JTAG Device Number	Module	Device	Function
0	All X3	Xilinx XCF02S FLASH ROM	PCI FPGA (Spartan3E) logic configuration ROM
1	All X3	Xilinx Spartan3E -250 FPGA (XC3S250E-4FTG256C)	Control FPGA for PCI Interface
2	X3-SD, X3-SDF	Xilinx Spartan3 -1000 FPGA (XC3S1000-4FGG456C) ** optional 2M device could be installed here	Application Logic
	All others	Xilinx Spartan3A DSP -1800 FPGA (XC3SD1800-4FGG676C) ** optional 3.4M device could be installed here	

FrameWork Logic

Many of the standard X3 XMC features are implemented in the application logic. This feature set includes a data flow, triggering features, and application-specific features. In many cases, this logic provides the features needed for a standard data acquisition function and is supported by software tools for data analysis and logging. In this manual, the FrameWork Logic features for each card are described in in general to explain the standard hardware functionality.

The *X3 FrameWork Logic User Guide* provides developers with the tools and know-how for developing custom logic applications. See this manual and the supporting source code for more information. The X3 XMC modules are supported by the FrameWork Logic Development tools that allow designs to be developed in HDL or MATLAB Simulink. Standard features are provided as components that may be included in custom applications, or further modified to meet specific design requirements.

Integrating with Host Cards and Systems

The X3 XMCs may be directly integrated PCI Express systems that support VITA 42.3 XMC modules. The host card must be both mechanically and electrically compatible or an adapter card must be used.

The XMC modules conform to IEEE 1386 specification for single width mezzanine cards . This specification is common to both PMC and XMC modules and specifies the size, mounting, mating card requirements for spacing and clearances.

There are several adapter cards that are used to integrate the XMC modules into other form-factor PCI Express systems, such as desktop systems.

There are also adapter cards to electrically adapter the PCI Express XMC modules in older PCI systems that use a bridge device between the two buses. PCI is not electrical

Host Type	Bus	Mechanical Form-factor	Adapter Required	Example card
XMC.3 module slot	PCI Express 1.0a	XMC, single width	None	Kontron CP6012 www.kontron.com Diversified Technology CPB4712 http://www.diversifiedtechnology.com/products/cpci/cpb4712.html
Desktop PC	PCI Express 1.0a	PCI Express Plug-in card	PCIe-XMC.3 adapter	Innovative 80172
Desktop PC	PCI 2.2	PCI Plug-in card	PCI-XMC.3 adapter	Innovative 80167
Compact PCI Express	PCI Express 1.0a	3U or 6U	CPCIe-XMC.3 adapter	TBD
Cabled PCI Express	PCI Express 1.0a	Cabled PCI Express to remote IO	Cable PCIe Adapter and XMC.3 carrier	Innovative 90181-0
PXI Express	Compact PCI Express	3U	3U PXIe Adapter	Innovative 80207

Embedded PC	Stand alone PC with dual XMC sites	Enclosure is 195 x 252 x 75 mm	-	Innovative 90200

Writing Custom Acquisition Applications

Most scientific and engineering applications require the acquisition and storage of data for analysis after the fact. Even in cases where most data analysis is done in place, there is usually a requirement that some data be saved to monitor the system. In many cases a pure data that does no immediate processing is the most common application.

A logger that saves all data to disk file is feasible at modest data rates. A dedicated RAID0 drive array partitioned as NTFS for data storage may be required if data rates approximate 80MBytes/sec.

Snap Example

The Snap example in the software distribution, demonstrates such functionality. It consists of a host program in Windows or Linux, which simultaneously works with user defined interface logic. It uses the Innovative Malibu software libraries to accomplish the tasks.

Tools Required

In general, writing applications for an X3 module requires the development of host program. This requires a development environment, a debugger, and a set of support libraries from Innovative.

Table 12. Development Tools.

Processor	**Development Environment**	**Innovative Toolset**	**Project Directory**
Host PC (Windows)	Borland Developers Studio C++	Malibu	Examples\Snap\Bcb
	Microsoft Visual Studio 2008		Examples\Snap\VC9
	Common Host Code		Examples\Snap\Common

Processor	**Development Environment**	**Innovative Toolset**	**Project Directory**
Host PC (Linux)	DialogBlocks	Malibu	Examples\Snap\DialogBlocks
	Common Host Code		Examples\Snap\Common

On the host side, the Malibu library is source code compatible with the above environments. The code that performs much of the actual functioning of the program, outside of the User Interface portion of the program, is therefore common code. Each project uses the same file to interact with the hardware and acquire data.

Chapter 1. Program Design

The Snap example is designed to allow repeated data reception operations on command from the host. As mentioned earlier, received data can be saved as Host disk files. When using modest samples rates, data can be logged to standard disk files. However, full bandwidth storage of multiple A/D channels can require up to 80 MB/s capacity, to a dedicated RAID0 drive array partitioned as NTFS for data storage may be required. The example application software is written to perform minimal processing of received data and is a suitable template for high-bandwidth applications.

The example uses various configuration commands to prepare the module for data flow. Parametric information is obtained from a Host GUI application, but the code is written to be GUI-agnostic. All board-specific I/O is performed within the ApplicationIo.cpp/.h unit. Data is transferred from the module to the Host as packets of Buffers.

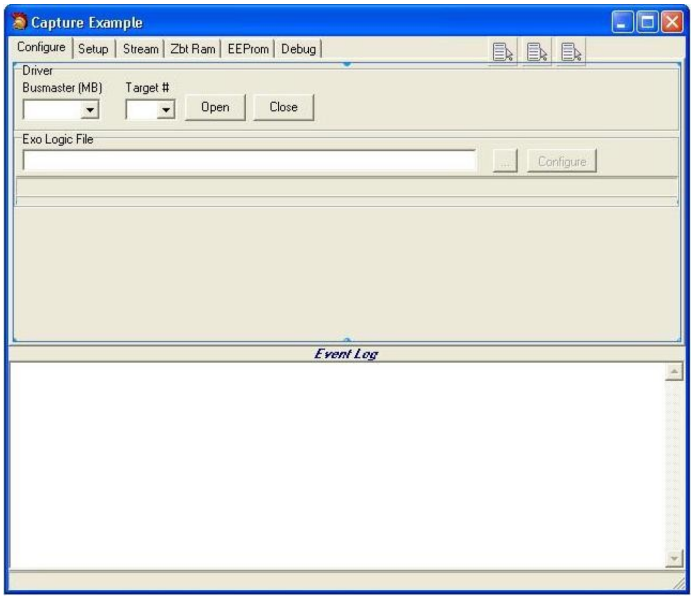
The Host Application

The picture to the right shows the main window of Snap example. This form is from the designer of the Borland Turbo C++ version of the example. It shows the layout of the controls of the User Interface. The timer, pop-up menu and folder icons to the upper right are non-visual components in Builder. Timer controls timer ticks and pop-up menu facilitate user to select channels on right click, where the folder controls the posting of a File Open Dialog box. They will not appear in the running application.

User Interface

This application has four tabs. Each tab has its own significance and usage, though few could be inter-related. All these tabs share a common area, which displays messages and feedback throughout the operation of the program. Logic Tab

Configure Tab



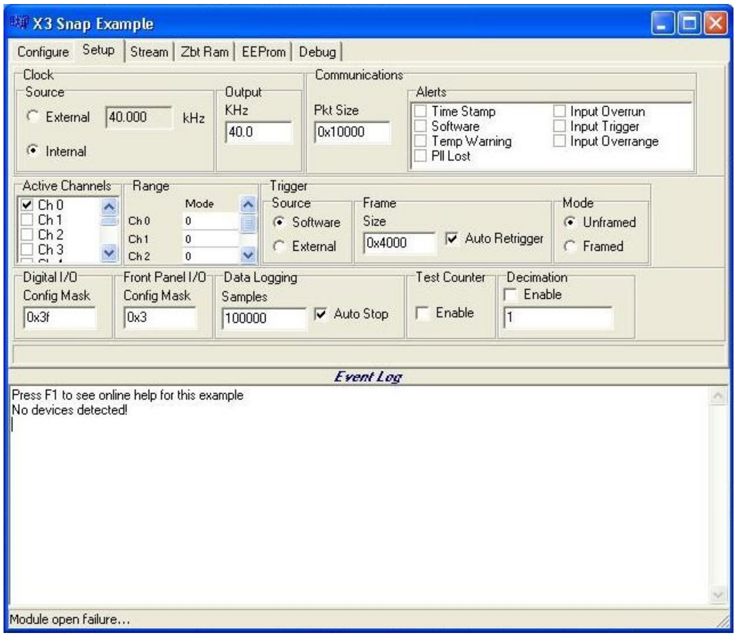
As soon as the application is launched, device driver is opened and hardware is attached to the selected target number. In this tab we configure user interface logic.

The target board number is set to zero. The order of the targets is determined by the location in the PCI bus, so it will remain unchanged from run to run.

While application is being launched, the device driver is automatically opened for the baseboard and internal resources are allocated for use. At this point, stream is simply connected to the board and board has been reset to be in known good state. Also, if ID ROM is properly initialized, module name and revision in addition to the “Device Opened” message is displayed in the message box.

Next, we load the desired user interface logic . The user logic for the module must be loaded at least once per session (it remains valid until power is removed from the board). Use “Configure” button is to load the logic from an BIT file.

Setup Tab



Clock
Source
○ External 40.000 kHz
● Internal
Output
KHz 40.0

Communications
Pkt Size 0x10000

Alerts
□ Time Stamp
□ Software
□ Temp Warning
□ Pll Lost
□ Input Overrun
□ Input Trigger
□ Input Overrange

Active Channels
☑ Ch 0
□ Ch 1
□ Ch 2
□ Ch 3

Range

	Mode
Ch 0	0
Ch 1	0
Ch 2	0

Trigger
Source
● Software
○ External
Frame
Size 0x4000 ☑ Auto Retrigger
Mode
● Unframed
○ Framed

Digital I/O
Config Mask 0x3f

Front Panel I/O
Config Mask 0x3

Data Logging
Samples 100000 ☑ Auto Stop

Test Counter
□ Enable

Decimation
□ Enable
1

```
Press F1 to see online help for this example
No devices detected!
```

Module open failure...

This tab has a set of controls that hold the parameters for data acquisition. These settings are delivered to the target and configure the target when streaming is initiated via controls on the Stream tab, described in the next section.

The setup tab contains a large number of controls used to configure the on-board timebase, alert notifications, analog channel selection, range and triggering, etc. Each of these controls is described below.

Clock Group. The module features an on-board AD9510 PLL which may be used as a sample clock during analog acquisition. Alternately, an external sample clock may be used. The `Clock | Source` radio control governs which timebase is used as the analog sample clock. If the internal PLL is selected, the sample rate entered in the Output | Khz edit control is used to program the PLL to generate the specified sample rate during acquisition. However, if the clock source is external, then the `Output | KHz` control is used to inform the program of your intended (external) sample rate. In that case, you are expected to supply a clock running at the rate listed in the `Clock | Source | KHz` control to the external clock input connector on the module.

Communications Group. All X3 modules support data transfer between Host memory and the on-board FPGA via a dedicated PCI Express bus interface. Data is transferred in packets, which consist of a two word header followed by a fixed-length data buffer. Header word zero contains the buffer length in bits 0:23 and a peripheral ID in bits 24:31.

The `Communications | Pkt Size` edit control specifies the size of the packets transferred between the target and the Host. Each packet transferred results in a Host interrupt, handled by the Malibu libraries. Consequently, larger packets amortize the Host interrupt processing more efficiently. However, packets are transferred using a contiguous, page-locked memory region of Host memory known as bus-master memory, which is allocated during installation via the `ReserveMemDsp.exe` applet (Windows). Since bus-master memory is Host memory, it is limited in size by the amount of physical memory installed in the PC. By default, 32 MBytes are allocated as bus-master memory. In practice, packets of 0x40000 bytes in size tend to provide good performance while fitting into available bus-master memory. Under Linux, the default is 4Mbytes of bus-master region and is being researched how to increase it; take this into consideration when specifying your packet size. Packet Size is defined in events, which corresponds to one sample of every enabled channel. It is recommended that the calculated packet size in bytes fits four to eight times into the allocated bus-master region.

Active Channels Group. The X3 module support simultaneous acquisition up to the maximum number of channels.

Trigger Group. Acquisition may be triggered using an external signal or via software. The `Trigger | Source` radio control provides the means of selection. Triggers act as a gate on data flow - no data flows until a trigger has been received. Triggers may be initiated via software or hardware, depending on the `Trigger | Source` control. If software, the application program must issue a command to initiate data flow. If hardware, a signal applied to the external trigger connector controls data flow.

Triggers are modal depending on the `Trigger | Mode` control. In `Unframed` mode, triggers are level sensitive and data flow proceeds while the trigger is in the high (active) state and stops while the trigger is in the low (inactive) state. This mode is ideal for conventional data acquisition applications. In `Framed` mode, triggers are rising edge sensitive. Upon detection of each edge, `Trigger | Frame | Count` samples are acquired from all active channels, then acquisition terminates until the next trigger edge is detected. If `Trigger | Frame | Auto Retrig` is checked and the `Trigger | Source` is software, the application automatically re-triggers upon completion of processing of the previous packet. This mode is ideal for application such as spectral analysis using fixed input buffers submitted to FFTs.

Digital I/O Group. These controls govern the configuration of the P16 DIO port on the module. The DIO port can be configured for input or output on a byte-wise basis, as a function of the configuration code in `Digital I/O | Config Mask`. See the DIO Control Register description (user logic offset 0x14) for details.

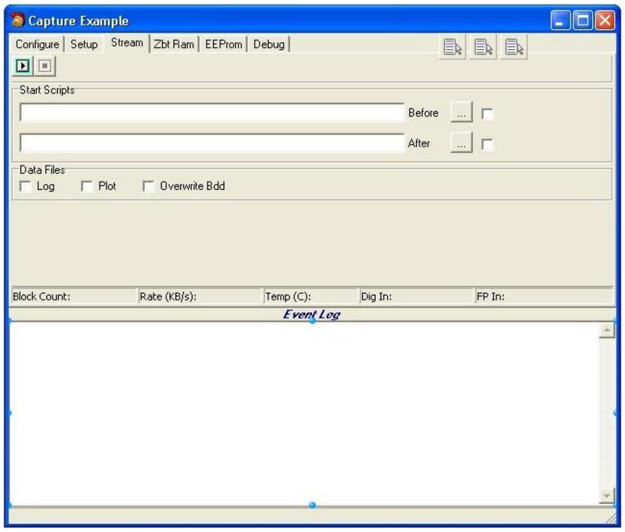
Front Panel I/O Group. These controls govern the configuration of the Front Panel DIO port on the module. The DIO port can be configured for input or output on a byte-wise basis, as a function of the configuration code in `Front Panel I/O | Config Mask`. See the Front Panel DIO Control Register description (user logic offset 0x07) for details.

Data Logging Group. These controls govern the size of data files created by the application containing packet data received from the module during real-time streaming. The value of `Data Logging | Samples` sets the upper-bound on the number of stored events (samples from each channel). If the `Data Logging | Auto Stop` checkbox is checked, streaming will automatically terminate once the specified number of events have been collected and logged to disk.

Test Counter Group. Use this control to enable a logic-specific test mode if you are developing custom FPGA logic. If you are using the stock factory-supplied logic, bit zero of the Test Register user logic offset 0x02 is controlled by Test Counter | Enable which forces an incremental ramp to replace A/D data from each channel.

Decimation Group. These controls govern the behavior enable the decimation logic. When enabled, only one of every Nth sample of acquired data is retained within the internal on-board FIFOs and sent to the Host PC via bus-mastering.

Data Streaming



Select the Stream tab. The controls on this tab control data flow. The meaning of each of the fields on this tab are explained below:
Data collection is initiated when the VCR Start button is pressed, and terminates when the VCR Stop button is pressed or when the amount of data specified in the Data Logging configuration controls is accumulated.

To accommodate custom logic development, the application supports execution of simple, user-authored scripts before and after the commencement of data flow. The `Start Scripts | Before` edit box specifies the full path spec to a text file containing valid script commands (described below) which will be executed prior to data flow. Similarly, the `Start Scripts | After` edit box specifies the file containing commands to be executed after data flow is underway.

The following script commands are supported:

-- l! (n a -) Store n to logic register address a

-- l@ (a - n) Fetch n from logic register address a

-- p! (n a -) Store n to port register address a

-- p@ (a - n) Fetch n from port register address a

-- ms (n -) Delay n milliseconds

All commands use postfix notation so parameters go before the command. For instance, `0x01, 0x02 l!` causes the value 0x01 to be stored to logic address 0x02.

The `Stream | Data Files | Log` check box controls whether received packets are logged in real time. If checked, data will be accumulated until the limit specified in the Data Logging | Samples edit box is reached.

The `Stream | Data Files | Plot` check box controls whether the BinView file viewer applet is invoked when streaming terminates to allow perusal of the acquired data stored in the disk file (not available under Linux).

The `Stream | Data Files | Overwrite BDD` check box controls whether a new BinView binary data descriptor file should be created as streaming terminates. Normally, this should be enabled so that a valid BDD is available for use by BinView when it is opened to view acquired data. But under some circumstances, such as when comments are added to the BDD file, it may be desirable to avoid re-creating the file each run.

During data flow, the number of received data packets, data transfer rate, board temperature, current DIO and Front Panel DIO pins state is shown in real time on the statistics status bar located at the bottom of the Streaming tab.

Ram Test

Select the `ZbtRam` tab. The control on this tab allows the onboard ZBT ram to be tested.

In practice, the ZbtRam is directly addressed by custom FPGA firmware. However, the stock logic provides means of accessing this RAM using methods in the module control object, to verify proper electrical operation.

EEPROM Access

Select the `EEPprom` tab. The controls on this tab allow the contents of the onboard EEPROM to be queried or changed.

The onboard EEPROM is used for non-volatile storage of module identification strings, digital calibration coefficients for each of the A/D channels and for a calibration coefficient for the reference clock for the onboard PLL. These values are determined during factory calibration and need not normally be changed by the user.

Debugging

Select the `Debug` tab. The controls on this tab support a few low-level debug operations to be performed.

A debug script may be executed at any time to perform low-level register fetches or stores to exercise custom FPGA firmware or determine the current hardware state. Unlike the stream scripts described earlier, this script executes manually (via the button), so you need not be streaming to put it to use.

A software alert may be generated by pressing the Software button. The value in the edit control to the right of this button is supplied as the code for the alert, which is returned and displayed in the log if software alerts are enabled for display.

Host Side Program Organization

With the exception of OS_Mb.lib (libOs_mb.a) and Analysis_Mb.lib(libAnalysys.a), the Malibu library is designed to be re-buildable in each of the different host environments: Borland C++ Builder, Microsoft Visual Studio 2003, Microsoft Visual Studio 2005 using the .NET UI, and GNU GCC(Linux). Because the library has a common interface in all environments, the code that interacts with Malibu is separated out into a class, ApplicationIo in the files ApplicationIo.cpp and .h. This class acts identically in all the platforms.

The Main form of the application creates an *ApplicationIo* to perform the work of the example. The UI can call the methods of the *ApplicationIo* to perform the work when, for example, a button is pressed or a control changed.

Sometimes, however, the *ApplicationIo* object needs to 'call back into' the UI. But since the code here is common, it can't use a pointer to the main window or form, as this would make *ApplicationIo* have to know details of Borland, VC, DialogBlocks(Linux) or the environment in use.

The standard solution to decouple the *ApplicationIo* from the form is to use an Interface class to hide the implementation. An interface class is an abstract class that defines a set of methods that can be called by a client class (here, *ApplicationIo*). The other class produces an implementation of the Interface by either multiple inheriting from the interface, or by creating a separate helper class object that derives from the interface. In either case the implementing class forwards the call to the UI form class to perform the action. *ApplicationIo* only has to know how to deal with a pointer to a class that implements the interface, and all UI dependencies are hidden.

The predefined *IUserInterface* interface class is defined in ApplicationIo.h. The constructor of *ApplicationIo* requires a pointer to the interface, which is saved and used to perform the actual updates to the UI inside of *ApplicationIo's* methods.

ApplicationIo

Initialization

The main form creates an ApplicationIo object in its constructor. The object creates a number of Malibu objects at once as can be seen from this detail from the header ApplicationIo.h.

```
PmcModule                           Module;
IUserInterface *                    UI;
Innovative::PacketStream            Stream;
IntArray                            _Rx;
unsigned int                        Cursor;
 ii64                              BlocksToLog;

bool                                Opened;
bool                                Stopped;
bool                                StreamConnected;
Innovative::StopWatch               Clock;
Innovative::DataLogger              Logger;
IntArray                            DataRead;
Innovative::BinView                 Graph;
Innovative::Scripter                Script;
float                               ActualSampleRate;
std::string                         Root;
Innovative::AveragedRate            Time;
double                              FBlockRate;
std::string                         FVersion;
Innovative::SoftwareTimer           Timer;
...
```

In Malibu, objects are defined to represent units of hardware as well as software units. The PmcModule, defined in Target.h, represents the X3 specifuc board. The PacketStream object encapsulates supported, board-specific operations. Scripter object can be used to add a simple scripting language to the application, for the purposes of performing hardware initialization during FPGA firmware development. Buffer class object can be used to access buffer contents.

In addition, under this constructor we hook up event handlers to various events.

```
// Hook script event handlers.
Script.OnCommand.SetEvent(this, &ApplicationIo::HandleScriptCommand);
Script.OnMessage.SetEvent(this, &ApplicationIo::HandleScriptMessage);
//
//  Configure Module Event Handlers
Module.Logic().OnFpgaFileReadProgress.SetEvent(this, &ApplicationIo::HandleProgress);
Module.Logic().OnFpgaFileReadComplete.SetEvent(this, &ApplicationIo::HandleParseComplete);
Module.Logic().OnFpgaParseProgress.SetEvent(this, &ApplicationIo::HandleProgress);
Module.Logic().OnFpgaParseComplete.SetEvent(this, &ApplicationIo::HandleParseComplete);
Module.Logic().OnFpgaParseMessage.SetEvent(this, &ApplicationIo::HandleLoadError);
Module.Logic().OnFpgaLoadProgress.SetEvent(this, &ApplicationIo::HandleProgress);
Module.Logic().OnFpgaLoadComplete.SetEvent(this, &ApplicationIo::HandleLoadComplete);
Module.Logic().OnFpgaLoadMessage.SetEvent(this, &ApplicationIo::HandleLoadError);
```

This code attaches script event handlers and X3 module logic loader's informational event handlers to their corresponding events. Malibu has a method where functions can be 'plugged into' the library to be called at certain times or in response to certain events detected. Events allow a tight integration between an application and the library. These events are informational messages issued by the scripting and logic loader feature of the module. They display feedback during the loading of the user logic and when script is used.

```
        //
        //  Alerts
        Module.Alerts().OnTimeStampRolloverAlert.SetEvent(this,
    &ApplicationIo::HandleTimestampRolloverAlert);
        Module.Alerts().OnSoftwareAlert.SetEvent(this, &ApplicationIo::HandleSoftwareAlert);
        Module.Alerts().OnWarningTemperature.SetEvent(this, &ApplicationIo::HandleWarningTempAlert);
        Module.Alerts().OnPllLost.SetEvent(this, &ApplicationIo::HandlePllLostAlert);
        Module.Alerts().OnInputFifoOverrun.SetEvent(this, &ApplicationIo::HandleInputFifoOverrunAlert);
        Module.Alerts().OnInputTrigger.SetEvent(this, &ApplicationIo::HandleInputTriggerAlert);
        Module.Alerts().OnInputOverrange.SetEvent(this, &ApplicationIo::HandleInputFifoOverrangeAlert);
```

This code attaches alert processing event handlers to their corresponding events. Alerts are packets that the module generates and sends to the Host as packets containing out-of-band information concerning the state of the module. For instance, if the analog inputs were subjected to an input over-range, an alert packet would be sent to the Host, interspersed into the data stream, indicating the condition. This information can be acted upon immediately, or simply logged along with analog data for subsequent post-analysis.

```
        Module.OnBeforeStreamStart.SetEvent(this, &ApplicationIo::HandleBeforeStreamStart);
        Module.OnBeforeStreamStart.Synchronize();
        Module.OnAfterStreamStart.SetEvent(this, &ApplicationIo::HandleAfterStreamStart);
        Module.OnAfterStreamStart.Synchronize();
        Module.OnAfterStreamStop.SetEvent(this, &ApplicationIo::HandleAfterStreamStop);
        Module.OnAfterStreamStop.Synchronize();
```

Similarly, HandleBeforeStreamStart, HandleAfterStreamStart and HandleAfterStreamStop handle events issued on before stream start, after stream start and after stream stop respectively. These handlers could be designed to perform multiple tasks as event occurs including displaying messages for user. These events are tagged as Synchronized, so Malibu will marshal the execution of the handlers for these events into the main thread context, allowing the handlers to perform user-interface operations.

The Stream object manages communication between the application and a piece of hardware. Separating the I/O into a separate class clarifies the distinction between an I/O protocol and the implementing hardware.

In Malibu, high rate data flow is controlled by one of a number of streaming classes. In this example we use the events of the PacketStream class to alert us when a packet arrives from the target. When a data packet is delivered by the data streaming system, OnDataAvailable event will be issued to process the incoming data. This event is set to be handled by HandleDataAvailable. After processing, the data will be discarded unless saved in the handler. Similarly, “OnDataRequired” event is handled by HandleDataRequired.

```
        //
        //  Configure Stream Event Handlers
        Stream.OnDataAvailable.SetEvent(this, &ApplicationIo::HandleDataAvailable);
        Stream.OnDataAvailable.Synchronize();
```

In this example, a Malibu SoftwareTimer object has been added to the ApplicationIo class to provide periodic status updates to the user interface. The handler below serves this purpose.

```
Timer.OnElapsed.SetEvent(this, &ApplicationIo::HandleTimer);
Timer.OnElapsed.Thunk();
```

An event is not necessarily called in the same thread as the UI. If it is not, and if you want to call a UI function in the handler you have to have the event synchronized with the UI thread. The call to Synchronize() directs the event to call the event handler in the main UI thread context. This results in a slight performance penalty, but allows us to call UI methods in the event handler freely.

Creating a hardware object does not attach it to the hardware. The object has to be explicitly opened. The Open() method open hardware.

```
//
//  Open Devices
Module.Target(Settings.Target);
Module.Open();
Module.Reset();
UI->Status("Module Device Opened...");
Opened = true;
```

This code shows how to open the device for streaming. Each baseboard has a unique code given in a PC. For instance, if there are three boards in a system, they will be targets 0,1 and 2. The order of the targets is determined by the location in the PCI bus, so it will remain unchanged from run to run. Moving the board to a different PCI slot may change the target identification. The Led property can be use to associate a target number with a physical board in a configuration.

Malibu method Open() is called to open the device driver for the baseboard and allocate internal resources for use. The next step is to call Reset() method which performs a board reset to put the board into a known good state. Note that reset will stop all data streaming through the bus-master interface and it should be called when data taking has been halted.

```
//
//  Connect Stream
Stream.ConnectTo(&Module);
StreamConnected = true;
UI->Status("Stream Connected...");

FHwPciClk = Module.Debug()->PciClockRate();
FHwBusWidth = Module.Debug()->PciBusWidth();
DisplayLogicVersion();

FChannels = Module.Input().Info().Channels().Channels();
```

Once the object is attached to actual physical device, the streaming controller associates with a baseboard by the ConnectTo() method. Once connected, the object is able to call into the baseboard for board-specific operations during data streaming. If an objects supports a stream type, this call will be implemented. Unsupported stream types will not compile.

```
//---------------------------------------------------------------------------
//  ApplicationIo::Close() --
//---------------------------------------------------------------------------

void ApplicationIo::Close()
{
    Stream->Disconnect();
    Board->Close();
```

```
        FOpened = false;
    }
```

Similarly, the Close() method closes the hardware. Inside this method, first we logically detach the streaming subsystem from its associated baseboard using Disconnect() method. Malibu method Close() is then used to detach the module from the hardware and release its resources.

Logic Loading

The user interface logic for the module must be loaded at least once per session (it remains valid until power is removed from the board). In the following code we show how to browse and configure the desired logic.

In the UI, when the logic browse button is pressed, LogicLoadBrowseBtnClick() method gets called as shown below.

```
    //---------------------------------------------------------------------------
    //  TMainForm::LogicLoadBrowseBtnClick() --
    //---------------------------------------------------------------------------

    void __fastcall TMainForm::LogicLoadBrowseBtnClick(TObject *Sender)
    {
        std::auto_ptr<TOpenDialog> Dialog(new TOpenDialog(NULL));
        Dialog->Filter = "Logic File (*.bit)|*.bit|All Files|*.*";
        Dialog->Title = "Select FPGA Logic File";
        if (LogicFilenameEdit->Text.Length())
            Dialog->InitialDir = ExtractFilePath(LogicFilenameEdit->Text);

        if (Dialog->Execute())
            LogicFilenameEdit->Text = Dialog->FileName;
    }
```

The code above opens a dialog allowing the user to browse for logic file. The filter property of this dialog masks out all the files in a folder other than bit file. If the user cancels out, no change will occur in the selection box. If logic file is selected then we will move on to the loading it.

```
    //---------------------------------------------------------------------------
    //  TMainForm::LogicLoadConfigBtnClick() --
    //---------------------------------------------------------------------------

    void __fastcall TMainForm::LogicLoadConfigBtnClick(TObject *Sender)
    {
        Io->LoadLogic();
    }
```

In UI, LogicLoadConfigBtnClick() shown above, is executed in response to the “Configure” button click. It immediately checks whether the device is opened and stream is connected. If the condition is true we exit the routine after logging the message in the message log. We can also do some more UI tricks here, such as setting up the progress bar limits and disabling the configure button etc. We further extract the file name from the Textbox and pass it to the ApplicationIo method LoadLogic() shown below.

```
    //---------------------------------------------------------------------------
    //  ApplicationIo::LoadLogic() -- Initiate Logic Load Process
    //---------------------------------------------------------------------------

    void  ApplicationIo::LoadLogic()
    {
        if (!Opened)
            {
```

```
            UI->Log("No module on specified target");
            return;
            }

        UI->Log("-----------------------------------------------");
        UI->Log("  Parsing Module logic file");

        UI->GetSettings();
        Module.Logic().ConfigureFpga(Settings.ExoFile);
    }
```

In this method, we make a call to the Malibu function ConfigureFpga() which allows new logic image to be loaded. This method takes name of the image file as an argument, which will be read and loaded into the interface logic. Logic loading triggers a series of events, which are managed by the background thread.

```
    //------------------------------------------------------------------------
    //  ApplicationIo::HandleProgress() --  Incremental logic load event
    //------------------------------------------------------------------------

    void  ApplicationIo::HandleProgress(ProcessProgressEvent & event)
    {
        UI->UpdateLogicLoadProgress(event.Percent);
    }
```

Process progress events are issued to give a percentage progress of the entire operation . These event are handled by HandleProgress(). This handler calls a UI method UpdateLogicLoadProgress() , where a Progress bar control is updated to give a visual effect of the loading progress.

```
    //----------------------------------------------------------------------------
    //  ApplicationIo::HandleLoadComplete() --  Logic load completion event
    //----------------------------------------------------------------------------

    void  ApplicationIo::HandleLoadComplete(ProcessCompletionEvent & event)
    {
        UI->Log("Load completed ok");

        DisplayLogicVersion();
    }
```

Finally, the logic loader issues a process completion event, when the load is complete. This event is handled by HandleLoadComplete as shown above. In this case, all we do is update the UI so the user can see that the logic configuration is complete and application status is idle. In other cases this could trigger the application to automatically perform additional tasks.

Starting Data flow

After downloading interface logic user can setup clocking and triggering options. The stream button then can be used to start streaming and thus data flow.

```
    //-------------------------------------------------------------------------
    //  ApplicationIo::StartStreaming() --  Initiate data flow
    //-------------------------------------------------------------------------

    void  ApplicationIo::StartStreaming()
    {
        if (!StreamConnected)
            {
            UI->Log("Stream not connected! -- Open the boards");
            return;
            }
            //
        //  Set up Parameters for Data Streaming
        //  ...First have UI get settings into our settings store
        UI->GetSettings();
```

Before we start streaming, all necessary parameters must be checked and loaded into option object. UI-> GetSettings() loads the settings information from the UI controls into the Settings structure in the ApplicationIo class.

```
    if (SampleRate() > Module.Input().Info().MaxRate())
        {
        UI->Log("Sample rate too high.");
        StopStreaming();
        UI->AfterStreamAutoStop();
        return;
        }
```

We insure that the sample rate specified by the GUI is within the capabilities of the module.

```
        if (Settings.Framed)
        {
               if (Settings.FrameCount < Settings.PacketSize)
            {
            UI->Log("Error: Frame count must exceed packet size");
            UI->AfterStreamAutoStop();
            return;
            }
        }
```

The module supports both framed and continuous triggering. In framed mode, each trigger event, whether external or software initiated, results in the acquisition of a fixed number of samples. In continuous mode, data flow continues whenever the trigger is active, and pauses while the trigger is inactive. The code above issues a warning if the trigger mode is framed and ill-formed.

```
    FBlockCount = 0;
    FBlockRate = 0;
    FTriggered = -1;
```

The class variables above are used to maintain counts of blocks received, reception rate and whether the module is currently triggered. These values are initialized prior to each streaming run.

```
        //
        //  Channel Enables
        for (int i = 0; i < Channels(); ++i)
               Module.Input().Info().Channels().Enabled(i, Settings.ActiveChannels[i] ? true :
false);

        int ActiveChannels = Module.Input().Info().Channels().ActiveChannels();
        if (!ActiveChannels)
               {
               UI->Log("Error: Must enable at least one channel");
               UI->AfterStreamAutoStop();
               return;
               }
```

The modules supports different quantity of A/D channels of simultaneous data flow. The previous call to GetSettings populated the Settings object with the number of channels to be enabled on this run. That information is used to enable the required channels via the Channels object within the Module.Input().Info() object.

```
// Packets scaled in units of events (samples per each enabled channel)
int SamplesPerWord = 1;
Module.ReturnPacketSize(Settings.PacketSize*ActiveChannels/SamplesPerWord + 2);
```

The size of the data packets sent from the module to the Host during streaming is programmable. This is helpful during framed acquisition, since the packet size can be tailored to match a multiple of the frame size, providing application notification on each acquired frame. In other applications, such as when an FFT is embedded within the FPGA, the packet size can be programmed to match the processing block size from the algorithm within the FPGA.

```
//
//  Start Loggers on active channels
if (Settings.PlotEnable)
       Graph.Quit();

if (Settings.LoggerEnable || Settings.PlotEnable)
       Logger.Start();

BlocksToLog = Settings.SamplesToLog/Settings.PacketSize
       + ((Settings.SamplesToLog%Settings.PacketSize) ? 1 : 0);

Stopped = false;
```

The example illustrates logging data to a disk file, with post-viewing of the acquired data using BinView. The code fragment above closes any pending instance of BinView and logger data files. BinView will not display data under Linux.

```
Module.Dio().DioPortConfig(Settings.DioConfig);
Module.FrontPanel().FrontPanelPortConfig(Settings.FrontPanelConfig);
```

The module supports programmable bit I/O, available on connector JP16 and on the Front Panel connector. The code fragment above programs the direction of these DIO bits in accordance with the settings from the GUI.

```
// Set test mode
Module.TestCounterEnable(Settings.TestCounterEnable);
```

For test purposes, the FPGA firmware supports replacement of analog input samples with ascending ramp data. If the test counter is enabled in the GUI, it is applied to the hardware using the preceeding code fragment.

```
// Set Decimation Factor, if enabled
    if (Settings.DecimationEnable)
     Module.Input().Decimation(Settings.DecimationFactor);
else
     Module.Input().Decimation(1);
```

The above code controls the desired decimation factor.

```
// Route clock to active analog devices
// Set reference based on clock source to obtain correct FrequencyActual
double reference;
if (Settings.SampleClockSource == 0)
       {
       reference = SampleRate() * Module.DecimationFactor(SampleRate());
       Module.Clock().OutputClock(Ad9511::oExternal);
       }
else
       {
       reference = Module.Input().Info().ReferenceClock();
       Module.Clock().OutputClock(Ad9511::oVco);
```

```
        }

// Apply timebase correction factor, if available
double correction = Settings.PllCorrection;
if (correction != correction)
        correction = 1.0;      // NaN, so fix it
Module.Clock().ReferenceCalibrationFactor(correction);
Module.Clock().Reference(reference);
Module.Clock().Frequency(SampleRate());
```

The module may accept an external sample clock but also features a programmable PLL clock source which may be used as a sample clock for the A/D input channels.

```
// All channels trigger together
Module.Input().ExternalTrigger((Settings.ExternalTrigger == 1));

// Frame count in units of packet elements
if (Settings.Framed)
        Module.Input().Framed(Settings.FrameCount);
else
        Module.Input().Unframed();
```

Samples will not be acquired until the channels are triggered. Triggering may be initiated by a software command or via an external input signal to the Trigger SMA connector. The code fragment above selects the trigger mode.

```
enum IUsesX3Alerts::AlertType Alert[] = {
        IUsesX3Alerts::alertTimeStampRollover, IUsesX3Alerts::alertSoftware,
        IUsesX3Alerts::alertWarningTemperature,
        IUsesX3Alerts::alertPllLost, IUsesX3Alerts::alertInputFifoOverrun,
        IUsesX3Alerts::alertInputTrigger, IUsesX3Alerts::alertInputOverrange };

for (unsigned int i = 0; i < Settings.AlertEnable.size(); ++i)
        Module.Alerts().AlertEnable(Alert[i], Settings.AlertEnable[i] ? true : false);
```

The fragment above enables alert generation by the module. The GUI control includes check boxes for each of the types of alerts of which the module is capable. The enabled state of the check boxes is copied into the Settings.AlertEnable array. This code fragment applies the state of each bit in that array to the Alerts() sub-object within the module. During streaming, an alert message will be sent to the Host tagged with a special alert packet ID (PID), to signify the alert condition.

```
//
//  Start Streaming
Stream.Start();
UI->Log("Stream Mode started");
UI->Status("Stream Mode started");
```

The Stream.Start command applies all of the above configuration settings to the module, then enables PCI data flow. However, samples will not be acquired until the module is triggered. .

```
ActualSampleRate = static_cast<float>(Module.Clock().FrequencyActual());

std::stringstream msg;
msg.precision(6);
msg << "Actual sampling rate: " << ActualSampleRate/1.e3 << " KHz";
UI->Log(msg.str());

FTicks = 0;
Timer.Enabled(true);
```

Handle Data Available

Once streaming is enabled and the module is triggered, data flow will commence. Samples will be accumulated into the onboard FIFO, then they are bus-mastered to the Host PC into page-locked, driver-allocated memory following a two -word header (data packets). Upon receipt of a data packet, Malibu signals the Stream.OnDataAvailable even. By hooking this event, your application can perform processing on each acquired packet. Note, however, that this event is signaled from within a background thread, so, you must not perform non-reentrant OS system calls (such as GUI updates) from within your handler unless you marshal said processing into the foreground thread context.

```
//---------------------------------------------------------------------------
//  ApplicationIo::HandleDataAvailable() --  Handle received packet
//---------------------------------------------------------------------------

void  ApplicationIo::HandleDataAvailable(PacketStreamDataEvent & Event)
{
    if (Stopped)
        return;

    static Buffer Packet;
    //
    //  Extract the packet from the Incoming Queue...
    Event.Sender->Recv(Packet);
    IntegerDG Packet_DG(Packet);
```

When the event is signaled, the data buffer must be copied from the system bus-master pool into an application buffer. The preceding code copies the packet into the local Buffer called Packet.

```
    //
    //  Process the data packet
    PacketBufferHeader PktBufferHdr(Packet);
    size_t Channel = PktBufferHdr.PeripheralId();

    // Discard packets from sources other than analog devices
       if (Channel >= Channels())
        return;
```

Each Buffer consists of a header and a body of data. The header may be interrogated to determine the data source. In the fragment above, packets containing peripheral IDs greater than the number of enabled channels are discarded. Consequently, alert packets are not retained or processed.

```
    // Calculate transfer rate in KB/s
    double Period = Time.Differential();
    if (Period)
        FBlockRate = Packet_DG.SizeInBytes() / (Period * 1.0e3);
```

The code fragment above calculates the nominal block processing rate. The AveragedRate object, Time, maintains a moving averaged filtered rate. This rate is stored in FBlockRate for use by display method of the GUI.

```
    if (Settings.LoggerEnable && !Logger.Logged)
        {
        // Start counter
        Clock.Start();

        std::stringstream msg;
        msg << "Packet size: " << Packet.Size() << " samples";
        UI->Log(msg.str());
        }
    // If enabled, log the data stream
    if (Settings.LoggerEnable || Settings.PlotEnable)
        if (FBlockCount < BlocksToLog)
            Logger.LogWithHeader(Packet);

    //
    //  Count the blocks gone by on each Channel...
    ++FBlockCount;
```

In this example, each received packet is logged to a disk file. The packet header and the body are written into the file, which implies that a post-analysis tool (such as BinView) will be used to parse channelized data from the file. Alternately, custom applications may use the Innovative::PacketDeviceMap object to conveniently extract channelized data from a packet data source.

```
        //
        //  Stop streaming when both Channels have passed their limit
           if (Settings.AutoStop && IsDataLoggingCompleted() && !Stopped)
                  {
                  // Stop counter and display it
                  double elapsed = Clock.Stop();

            StopStreaming();
            UI->AfterStreamAutoStop();
            UI->Log("Stream Mode Stopped automatically");
            UI->Log(std::string("Elasped (S): ") + FloatToString(elapsed));
            }
```

Packets are processed until a specified amount of data is logged or the GUI Stop button is pressed.

```
        // Auto-analyze and retrigger in framed mode
        if (!Settings.Framed)
            return;

        if ((Settings.ExternalTrigger == 0) && Settings.AutoTrigger)
                  {
            __int64 samples = FBlockCount * Settings.PacketSize;
            int triggers = static_cast<int>(samples/Settings.FrameCount);

            if (triggers != FTriggered)
                SoftwareTrigger();
            }
    }
```

In the event that were operating in framed trigger mode, the example code re-asserts a software trigger each time a frames-worth of data packets have been received. If we're in continuous mode, no action need be performed to sustain data flow.

EEProm Access

Each PMC module contains an IDROM region that can be used to write information associated with the module. In the next line of code we make a call to Malibu method IdRom(), which returns an object that acts as interface to that region. The following methods illustrate how to write and read information from IDROM. StoreToRom() and ReadRom() are the two IdRom methods used to save and retrieve data to/from memory.

```
    //---------------------------------------------------------------------------
    //  ApplicationIo::WriteRom() --  Write rom using relevant settings
    //---------------------------------------------------------------------------
```

```
void ApplicationIo::WriteRom()
{
    Module.IdRom().Name(Settings.ModuleName);
    Module.IdRom().Revision(Settings.ModuleRevision);
    Module.Clock().ReferenceCalibrationFactor(Settings.PllCorrection);

    for (size_t range = 0; range < Ranges(); ++range)
        {
        for (size_t ch = 0; ch < Channels(); ++ch)
            {
            Module.Input().Gain(range, ch, Settings.Gain[range][ch]);
            Module.Input().Offset(ch, Settings.AdcOffset[range][ch]);
            }
        Module.Input().Calibrated(range, Settings.Calibrated);
        }
    Module.IdRom().StoreToRom();
}

//---------------------------------------------------------------------------
//  ApplicationIo::ReadRom() --  Read rom and update relevant settings
//---------------------------------------------------------------------------

void ApplicationIo::ReadRom()
{
    Module.IdRom().LoadFromRom();

    Settings.ModuleName = Module.IdRom().Name();
    Settings.ModuleRevision = Module.IdRom().Revision();
    Settings.PllCorrection = static_cast<float>(Module.Clock().ReferenceCalibrationFactor());

    bool calibrated = true;
    for (size_t range = 0; range < Ranges(); ++range)
        {
        for (size_t ch = 0; ch < Channels(); ++ch)
            {
            Settings.Gain[range][ch] = Module.Input().Gain(range, ch);
            Settings.Offset[range][ch] = Module.Input().Offset(range, ch);
            }

        calibrated &= Module.Input().Calibrated(range);
        }

    Settings.Calibrated = calibrated;
}
```

Writing Custom Playback Applications

This chapter explains how to write an application that plays a pre-defined waveform, the source of the waveform data maybe a disk file or calculated by the program on a per-buffer basis.

Wave Example

The Wave example, in the software distribution, demonstrates such functionality. It consists of a host program in Windows or Linux, which simultaneously works with user defined interface logic. It uses the Innovative Malibu software libraries to accomplish the tasks.

Tools Required

In general, writing applications for an X3 module requires the development of host program. This requires a development environment, a debugger, and a set of support libraries from Innovative.

Table 13. Development Tools.

Processor	**Development Environment**	**Innovative Toolset**	**Project Directory**
Host PC (Windows)	Borland Developers Studio C++	Malibu	Examples\Snap\Bcb
	Microsoft Visual Studio 2008		Examples\Snap\VC9
	Common Host Code		Examples\Snap\Common

Processor	**Development Environment**	**Innovative Toolset**	**Project Directory**
Host PC (Linux)	DialogBlocks	Malibu	Examples\Snap\DialogBlocks
	Common Host Code		Examples\Snap\Common

On the host side, the Malibu library is source code compatible with the above environments. The code that performs much of the actual functioning of the program, outside of the User Interface portion of the program, is therefore common code. Each project uses the same file to interact with the hardware and acquire data.

Program Design

The Wave example is designed to allow repeated data playback operations on command from the host. As mentioned earlier, data can be sourced from disk file or calculated on the fly on a per buffer (packet) basis. The example application software is written to perform minimal processing of played data and is a suitable template for high-bandwidth applications.

The example uses various configuration commands to prepare the module for data flow. Parametric information is obtained from a Host GUI application, but the code is written to be GUI-agnostic. All board-specific I/O is performed within the ApplicationIo.cpp/.h unit. Data is transferred from the Host to the module as packets of Buffers.

The Host Application

The picture to the right shows the main window of Wave example. This form is from the designer of the Borland Turbo C++ version of the example. It shows the layout of the controls of the User Interface. The timer, pop-up menu and folder icons to the upper right are non-visual components in Builder. Timer controls timer ticks and pop-up menu facilitate user to select channels on right click, where the folder controls the posting of a File Open Dialog box. They will not appear in the running application.

User Interface

This application has four tabs. Each tab has its own significance and usage, though few could be inter-related. All these tabs share a common area, which displays messages and feedback throughout the operation of the program. Logic Tab

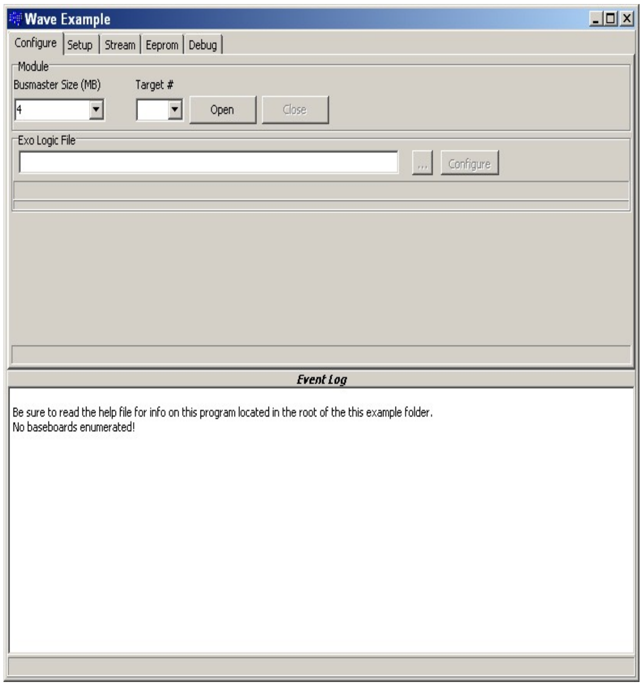
Configure Tab

As soon as the application is launched, device driver is opened and hardware is attached to the selected target number. In this tab we configure user interface logic.

The target board number is set to zero. The order of the targets is determined by the location in the PCI bus, so it will remain unchanged from run to run.

While application is being launched, the device driver is automatically opened for the baseboard and internal resources are allocated for use. At this point, stream is simply connected to the board and board has been reset to be in known good state. Also, if ID ROM is properly initialized, module name and revision in addition to the "Device Opened" message is displayed in the message box.

Next, we load the desired user interface logic . The user logic for the module must be loaded at least once per

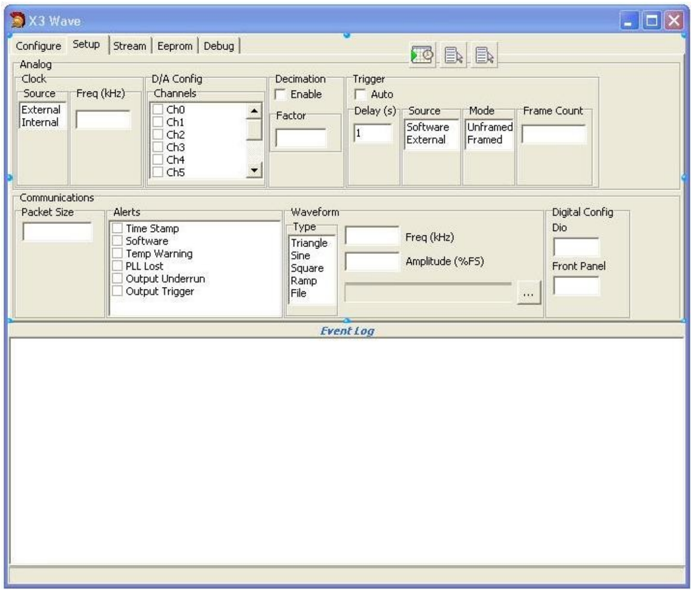


Busmaster Size (MB): 4

Be sure to read the help file for info on this program located in the root of the this example folder.
No baseboards enumerated!

session (it remains valid until power is removed from the board). Use “Configure” button is to load the logic from an BIT file.

Setup Tab



This tab has a set of controls that hold the parameters for data playback. These settings are delivered to the target and configure the target when streaming is initiated via controls on the Stream tab, described in the next section.

The setup tab contains a large number of controls used to configure the on-board timebase, alert notifications, analog channel selection, range and triggering, etc. Each of these controls is described below.

Clock Group. The module features an on-board AD9510 PLL which may be used as a sample clock during analog acquisition. Alternately, an external sample clock may be used. The `Clock | Source` radio control governs which timebase is used as the analog sample clock. If the internal PLL is selected, the sample rate entered in the Output | Khz edit control is used to program the PLL to generate the specified sample rate during acquisition. However, if the clock source is external, then the `Output | KHz` control is used to inform the program of your intended (external) sample rate. In that case, you are expected to supply a clock running at the rate listed in the `Clock | Source | KHz` control to the external clock input connector on the module.

Active Channels Group. The X3 modules support simultaneous playback to all their channels.

Decimation Group. These controls govern the behavior enable the decimation logic. When enabled, the DAC(s) update rate will be affected, thus the interrupt to the Host PC will be decreased. All waveform samples will be deliver to the DAC(s) but the DAC(s) will be clocked at a slower rate.

Trigger Group. Playback may be TRIGGERED using an external signal or via software. The `Trigger | Source` list control provides the means of selection. Triggers act as a gate on data flow - no data flows until a trigger has been received. Triggers may be initiated via software or hardware, depending on the `Trigger | Source` control. If software, the application program must issue a command to initiate data flow. If hardware, a signal applied to the external trigger connector controls data flow.

Triggers are modal depending on the `Trigger | Mode` control. In `Unframed` mode, triggers are level sensitive and data flow proceeds while the trigger is in the high (active) state and stops while the trigger is in the low (inactive) state. This mode is ideal for conventional data playback applications. In `Framed` mode, triggers are rising edge sensitive. Upon detection of each edge, `Trigger | Frame Count` samples are played from all active channels, then playback terminates until the next trigger edge is detected. If `Trigger | Auto` is checked and the `Trigger | Source` is software, the application automatically re-triggers upon completion of processing of the previous packet. This mode is ideal for application such as stimulus response, etc .

Communications Group. All X3 modules support data transfer between Host memory and the on-board FPGA via a dedicated PCI Express bus interface. Data is transferred in packets, which consist of a two word header followed by a fixed-length data buffer. Header word zero contains the buffer length in bits 0:23 and a peripheral ID in bits 24:31.

The `Communications | Pkt Size` edit control specifies the size of the packets transferred between the target and the Host. Each packet transferred results in a Host interrupt, handled by the Malibu libraries. Consequently, larger packets amortize the Host interrupt processing more efficiently. However, packets are transferred using a contiguous, page-locked memory region of Host memory known as bus-master memory, which is allocated during installation via the `ReserveMemDsp.exe` applet (Windows). Since bus-master memory is Host memory, it is limited in size by the amount of physical memory installed in the PC. By default, 32 Mbytes (4MBytes observed under Linux) are allocated as bus-master memory, which implies that the Pkt Size must be restricted to fit within this region. The packet size is in terms of "samples per enabled channel", so if a module has 4 enabled channels of 16 bits each, then a packet size of 1000 translates to 2000 32-bit words. Thus we recommend a packets size that fits eight times in the bus-master region. So if your bus-master region is 32 Mbytes, then 4 Mbytes is a good size, packets of less data will cause more interrupts to the host PC and thus less time for your software to do other tasks.

Alerts Group. Enables out of band information packets to be delivered to the Host PC informing different conditions of the hardware.

Waveform Group. Selects the type of waveform to be calculated by the software, also external files can be used as the data source.

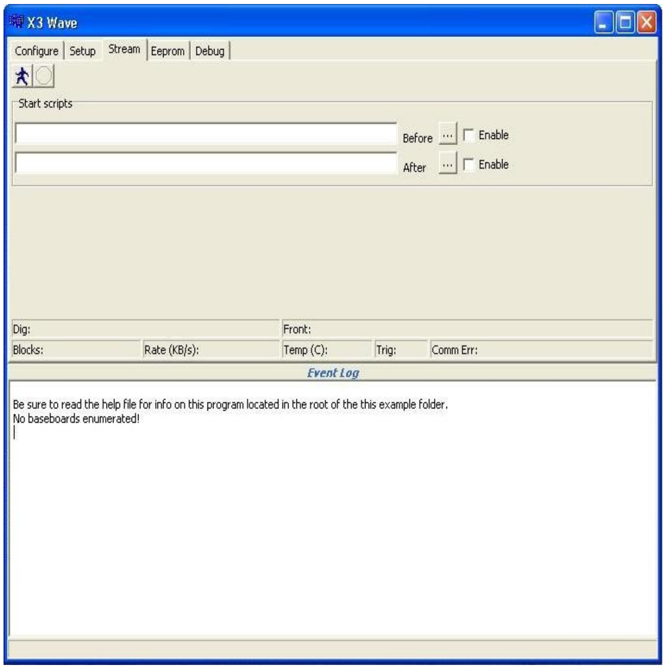
Frequency and Amplitude Group. They determine, in the case where data source is not a disk file, the output waveform's frequency and percentage of full scale.

Digital I/O Group. This control governs the configuration of the P16 DIO port on the module. The DIO port can be configured for input or output on a byte-wise basis, as a function of the configuration code in `Digital I/O | Config Mask`. See the DIO Control Register description (user logic offset 0x14) for details.

Front Panel I/O Group. This control governs the configuration of the Front Panel DIO port on the module. The DIO port can be configured for input or output on a byte-wise basis, as a function of the configuration code in `Front Panel I/O | Config Mask`. See the Front Panel DIO Control Register description (user logic offset 0x07) for details.

Data Streaming

Select the Stream tab. The controls on this tab control data flow. The meaning of each of the fields on this tab are explained below:
Data playback is initiated when the “running man” button is pressed, and terminates when the Stop button is pressed (Unframed mode) or when an entire frame has played and trigger is not in “re-trigger” mode (framed mode).



Be sure to read the help file for info on this program located in the root of the this example folder.
No baseboards enumerated!

To accommodate custom logic development, the application supports execution of simple, user-authored scripts before and after the commencement of data flow. The `Start Scripts | Before` edit box specifies the full path spec to a text file containing valid script commands (described below) which will be executed prior to data flow. Similarly, the `Start Scripts | After` edit box specifies the file containing commands to be executed after data flow is underway.

The following script commands are supported:

-- l! (n a -) Store n to logic register address a

-- l@ (a - n) Fetch n from logic register address a

-- p! (n a -) Store n to port register address a

-- p@ (a - n) Fetch n from port register address a

-- ms (n -) Delay n milliseconds

All commands use postfix notation so parameters go before the command. For instance, `0x01, 0x02 l!` causes the value 0x01 to be stored to logic address 0x02.

During data flow, the number of played data packets, data transfer rate, board temperature, current DIO and Front Panel DIO pins state is shown in real time on the statistics status bar located at the bottom of the Streaming tab.

EEPROM Access

Select the `EEPprom` tab. The controls on this tab allow the contents of the onboard EEPROM to be queried or changed.

The onboard EEPROM is used for non-volatile storage of module identification strings, digital calibration coefficients for each of the A/D channels and for a calibration coefficient for the reference clock for the onboard PLL. These values are determined during factory calibration and need not normally be changed by the user.

Debugging

Select the `Debug` tab. The controls on this tab support a few low-level debug operations to be performed.

A debug script may be executed at any time to perform low-level register fetches or stores to exercise custom FPGA firmware or determine the current hardware state. Unlike the stream scripts described earlier, this script executes manually (via the button), so you need not be streaming to put it to use.

A software alert may be generated by pressing the Software button. The value in the edit control to the right of this button is supplied as the code for the alert, which is returned and displayed in the log if software alerts are enabled for display.

Host Side Program Organization

With the exception of OS_Mb.lib (libOs_mb.a) and Analysis_Mb.lib(libAnalysys.a), the Malibu library is designed to be re-buildable in each of the different host environments: Borland C++ Builder, Microsoft Visual Studio 2003, Microsoft Visual Studio 2005 using the .NET UI, and GNU GCC(Linux). Because the library has a common interface in all environments, the code that interacts with Malibu is separated out into a class, ApplicationIo in the files ApplicationIo.cpp and .h. This class acts identically in all the platforms.

The Main form of the application creates an *ApplicationIo* to perform the work of the example. The UI can call the methods of the *ApplicationIo* to perform the work when, for example, a button is pressed or a control changed.

Sometimes, however, the *ApplicationIo* object needs to 'call back into' the UI. But since the code here is common, it can't use a pointer to the main window or form, as this would make *ApplicationIo* have to know details of Borland, VC, DialogBlocks(Linux) or the environment in use.

The standard solution to decouple the *ApplicationIo* from the form is to use an Interface class to hide the implementation. An interface class is an abstract class that defines a set of methods that can be called by a client class (here, *ApplicationIo*). The other class produces an implementation of the Interface by either multiple inheriting from the interface, or by creating a separate helper class object that derives from the interface. In either case the implementing class forwards the call to the UI form class to perform the action. *ApplicationIo* only has to know how to deal with a pointer to a class that implements the interface, and all UI dependencies are hidden.

The predefined *IUserInterface* interface class is defined in ApplicationIo.h. The constructor of *ApplicationIo* requires a pointer to the interface, which is saved and used to perform the actual updates to the UI inside of *ApplicationIo's* methods.

ApplicationIo

Initialization

The main form creates an ApplicationIo object in its constructor. The object creates a number of Malibu objects at once as can be seen from this detail from the header ApplicationIo.h.

```
PmcModule                        Module;
Innovative::PacketStream         Stream;
IUserInterface           *       UI;
Innovative::Scripter             Script;
Innovative:: Buffer   *          Packet;
```

```
        Innovative::AveragedRate        Time;
        Innovative::SoftwareTimer       Timer;
         ...
```

In Malibu, objects are defined to represent units of hardware as well as software units. The PmcModule, defined in Target.h, represents the X3 specific board. The PacketStream object encapsulates supported, board-specific operations. Scripter object can be used to add a simple scripting language to the application, for the purposes of performing hardware initialization during FPGA firmware development. Buffer class object can be used to access buffer contents.

In addition, under the "Open()" method we hook up event handlers to various events.

```
    // Hook script event handlers.
    Script.OnCommand.SetEvent(this, &ApplicationIo::HandleScriptCommand);
    Script.OnMessage.SetEvent(this, &ApplicationIo::HandleScriptMessage);
    //
    //  Configure Module Event Handlers
    Module.Logic().OnFpgaFileReadProgress.SetEvent(this, &ApplicationIo::HandleProgress);
    Module.Logic().OnFpgaFileReadComplete.SetEvent(this, &ApplicationIo::HandleParseComplete);
    Module.Logic().OnFpgaParseProgress.SetEvent(this, &ApplicationIo::HandleProgress);
    Module.Logic().OnFpgaParseComplete.SetEvent(this, &ApplicationIo::HandleParseComplete);
    Module.Logic().OnFpgaParseMessage.SetEvent(this, &ApplicationIo::HandleLoadError);
    Module.Logic().OnFpgaLoadProgress.SetEvent(this, &ApplicationIo::HandleProgress);
    Module.Logic().OnFpgaLoadComplete.SetEvent(this, &ApplicationIo::HandleLoadComplete);
    Module.Logic().OnFpgaLoadMessage.SetEvent(this, &ApplicationIo::HandleLoadError);
```

This code attaches script event handlers and X3 module logic loader's informational event handlers to their corresponding events. Malibu has a method where functions can be 'plugged into' the library to be called at certain times or in response to certain events detected. Events allow a tight integration between an application and the library. These events are informational messages issued by the scripting and logic loader feature of the module. They display feedback during the loading of the user logic and when script is used.

```
          //
          //  Alerts
          Module.Alerts().OnTimeStampRolloverAlert.SetEvent(this,
      &ApplicationIo::HandleTimestampRolloverAlert);
          Module.Alerts().OnSoftwareAlert.SetEvent(this, &ApplicationIo::HandleSoftwareAlert);
          Module.Alerts().OnWarningTemperature.SetEvent(this, &ApplicationIo::HandleWarningTempAlert);
          Module.Alerts().OnPllLost.SetEvent(this, &ApplicationIo::HandlePllLostAlert);
          Module.Alerts().OnInputFifoOverrun.SetEvent(this, &ApplicationIo::HandleInputFifoOverrunAlert);
          Module.Alerts().OnInputTrigger.SetEvent(this, &ApplicationIo::HandleInputTriggerAlert);
          Module.Alerts().OnInputOverrange.SetEvent(this, &ApplicationIo::HandleInputFifoOverrangeAlert);
```

This code attaches alert processing event handlers to their corresponding events. Alerts are packets that the module generates and sends to the Host as packets containing out-of-band information concerning the state of the module. For instance, if the analog inputs were subjected to an input over-range, an alert packet would be sent to the Host, interspersed into the data stream, indicating the condition. This information can be acted upon immediately, or simply logged along with analog data for subsequent post-analysis.

```
          Module.OnBeforeStreamStart.SetEvent(this, &ApplicationIo::HandleBeforeStreamStart);
          Module.OnBeforeStreamStart.Synchronize();
          Module.OnAfterStreamStart.SetEvent(this, &ApplicationIo::HandleAfterStreamStart);
          Module.OnAfterStreamStart.Synchronize();
          Module.OnAfterStreamStop.SetEvent(this, &ApplicationIo::HandleAfterStreamStop);
          Module.OnAfterStreamStop.Synchronize();
```

Similarly, HandleBeforeStreamStart, HandleAfterStreamStart and HandleAfterStreamStop handle events issued on before stream start, after stream start and after stream stop respectively. These handlers could be designed to perform multiple tasks as event occurs including displaying messages for user. These events are tagged as Synchronized, so Malibu will marshall the execution of the handlers for these events into the main thread context, allowing the handlers to perform user-interface operations.

The Stream object manages communication between the application and a piece of hardware. Separating the I/O into a separate class clarifies the distinction between an I/O protocol and the implementing hardware.

In Malibu, high rate data flow is controlled by one of a number of streaming classes. In this example we use the events of the PacketStream class to alert us when a packet is required by the target. When a data packet is delivered by the data streaming system, OnDataRequired event will be issued to supply more data. This event is set to be handled by HandleDataRequired.

```
//
//  Configure Stream Event Handlers
Stream.OnDataRequired.SetEvent(this, &ApplicationIo::HandleDataRequired);
```

In this example, a Malibu SoftwareTimer object has been added to the ApplicationIo class to provide periodic status updates to the user interface. The handler below serves this purpose.

```
Timer.OnElapsed.SetEvent(this, &ApplicationIo::HandleTimer);
Timer.OnElapsed.Thunk();
```

An event is not necessarily called in the same thread as the UI. If it is not, and if you want to call a UI function in the handler you have to have the event synchronized with the UI thread. The call to Synchronize() directs the event to call the event handler in the main UI thread context. This results in a slight performance penalty, but allows us to call UI methods in the event handler freely.

Creating a hardware object does not attach it to the hardware. The object has to be explicitly opened. The Open() method open hardware.

```
//
//  Open Devices
Module.Target(Settings.Target);
Module.Open();
Module.Reset();
UI->Status("Module Device Opened...");
Opened = true;
```

This code shows how to open the device for streaming. Each baseboard has a unique code given in a PC. For instance, if there are three boards in a system, they will be targets 0,1 and 2. The order of the targets is determined by the location in the PCI bus, so it will remain unchanged from run to run. Moving the board to a different PCI slot may change the target identification. The Led property can be use to associate a target number with a physical board in a configuration.

Malibu method Open() is called to open the device driver for the baseboard and allocate internal resources for use. The next step is to call Reset() method which performs a board reset to put the board into a known good state. Note that reset will stop all data streaming through the busmaster interface and it should be called when data taking has been halted.

```
//
//  Connect Stream
Stream.ConnectTo(&Module);
StreamConnected = true;
UI->Status("Stream Connected...");
PrefillPacketCount = Stream.PrefillPacketCount();
FHwPciClk = Module.Debug()->PciClockRate();
FHwBusWidth = Module.Debug()->PciBusWidth();
DisplayLogicVersion();

FChannels = Module.Input().Info().Channels().Channels();
```

Once the object is attached to actual physical device, the streaming controller associates with a baseboard by the ConnectTo() method. Once connected, the object is able to call into the baseboard for board-specific operations during data streaming. If an objects supports a stream type, this call will be implemented. Unsupported stream types will not compile.

The prefill method is used to fill the bus-master region with default data so that an immediate underflow may be avoided.

```
//---------------------------------------------------------------------------
// ApplicationIo::Close()
//---------------------------------------------------------------------------

void ApplicationIo::Close()
{
    Stream.Disconnect();
    Module.Close();
    FStreamConnected = false;
    FOpened = false;
    UI->Status("Stream Disconnected...");
}
```

Similarly, the Close() method closes the hardware. Inside this method, first we logically detach the streaming subsystem from its associated baseboard using Disconnect() method. Malibu method Close() is then used to detach the module from the hardware and release its resources.

Logic Loading

The user interface logic for the module must be loaded at least once per session (it remains valid until power is removed from the board). In the following code we show how to browse and configure the desired logic.

In the UI, when the logic browse button is pressed, LogicLoadBrowseBtnClick() method gets called as shown below.

```
//---------------------------------------------------------------------------
//  TMainForm::LogicLoadBrowseBtnClick() --
//---------------------------------------------------------------------------

void __fastcall TMainForm::LogicLoadBrowseBtnClick(TObject *Sender)
{
    std::auto_ptr<TOpenDialog> Dialog(new TOpenDialog(NULL));
    Dialog->Filter = "Logic File (*.bit)|*.bit|Logic File (*.exo)|(*.exo)|All Files|*.*";
    Dialog->Title = "Select FPGA Logic File";
    if (LogicFilenameEdit->Text.Length())
        Dialog->InitialDir = ExtractFilePath(LogicFilenameEdit->Text);

    if (Dialog->Execute())
        LogicFilenameEdit->Text = Dialog->FileName;
}
```

The code above opens a dialog allowing the user to browse for logic file. The filter property of this dialog masks out all the files in a folder other than bit file or exo file. If the user cancels out, no change will occur in the selection box. If logic file is selected then we will move on to the loading it.

```
//---------------------------------------------------------------------------
//  TMainForm::LogicLoadConfigBtnClick() --
//---------------------------------------------------------------------------

void __fastcall TMainForm::LogicLoadConfigBtnClick(TObject *Sender)
{
    Io->LoadLogic();
}
```

In UI, LogicLoadConfigBtnClick() shown above, is executed in response to the “Configure” button click. It immediately checks whether the device is opened and stream is connected. If the condition is true we exit the routine after logging the message in the message log. We can also do some more UI tricks here, such as setting up the progress bar limits and disabling the configure button etc. We further extract the file name from the Textbox and pass it to the ApplicationIo method LoadLogic() shown below.

```
//---------------------------------------------------------------------------
//  ApplicationIo::LoadLogic() -- Initiate Logic Load Process
//---------------------------------------------------------------------------

void  ApplicationIo::LoadLogic()
{
    if (!Opened)
        {
        UI->Log("No module on specified target");
        return;
        }

    UI->Log("-----------------------------------------------");
    UI->Log("  Parsing Module logic file");

    UI->GetSettings();
    Module.Logic().ConfigureFpga(Settings.ExoFile);
}
```

In this method, we make a call to the Malibu function ConfigureFpga() which allows new logic image to be loaded. This method takes name of the image file as an argument, which will be read and loaded into the interface logic. Logic loading triggers a series of events, which are managed by the background thread.

```
//--------------------------------------------------------------------------
//  ApplicationIo::HandleProgress() --  Incremental logic load event
//--------------------------------------------------------------------------

void  ApplicationIo::HandleProgress(ProcessProgressEvent & event)
{
    UI->UpdateLogicLoadProgress(event.Percent);
}
```

Process progress events are issued to give a percentage progress of the entire operation . These event are handled by HandleProgress(). This handler calls a UI method UpdateLogicLoadProgress() , where a Progress bar control is updated to give a visual effect of the loading progress.

```
//------------------------------------------------------------------------------
//  ApplicationIo::HandleLoadComplete() --  Logic load completion event
//------------------------------------------------------------------------------

void  ApplicationIo::HandleLoadComplete(ProcessCompletionEvent & event)
{
    UI->Log("Load completed ok");

    DisplayLogicVersion();
    }
```

Finally, the logic loader issues a process completion event, when the load is complete. This event is handled by HandleLoadComplete as shown above. In this case, all we do is update the UI so the user can see that the logic configuration is complete and application status is idle. In other cases this could trigger the application to automatically perform additional tasks.

Starting Data flow

After downloading interface logic user can setup clocking and triggering options. The stream button then can be used to start streaming and thus data flow.

```
//---------------------------------------------------------------------------
// ApplicationIo::StartStreaming()
//---------------------------------------------------------------------------

bool ApplicationIo::StartStreaming()
{
    //
    //  Set up Parameters for Data Streaming
    //  ...First have UI get settings into our settings store
    UI->GetSettings();
```

Before we start streaming, all necessary parameters must be checked and loaded into option object. UI-> GetSettings() loads the settings information from the UI controls into the Settings structure in the ApplicationIo class.

```
    if (!FStreamConnected)
        {
        Log("Stream not connected! -- Open the boards");
        return false;
        }

    //
    // Make sure packets fit nicely in BM region.
       if (FBusmasterSize/4 < (unsigned int)Settings.StreamPacketSize)
        {
        Log("Error: Packet size is larger than recommended size");
        return false;
        }
```

Next we test that the Stream object has been successfully connected to the module object (happens at Open()). And then we verify that at least four packets will fit in the bus-master are.

```
    if (SampleRate() > Module.Output().Info().MaxRate())
        {
        Log("Sample rate too high.");
        StopStreaming();
        UI->AfterStreamStop();
        return false;
        }

    // Clock config
    ActualSampleRate = SampleRate();

       // Route clock to active analog devices
       // Set reference based on clock source to obtain correct FrequencyActual
       double reference;
       if (Settings.SampleClockSource == 0)
               {
               reference = SampleRate() * Module.Output().Info().ClockFactor();
               Module.Clock().OutputClock(PmcModule::Timebase::oExternal);
```

```
                }
        else
                {
                reference = Module.Output().Info().ReferenceClock();
                Module.Clock().OutputClock(PmcModule::Timebase::oVco);
                }

        Module.Clock().Reference(reference);
        Module.Clock().Frequency(SampleRate());
```

The module may accept an external sample clock but also features a programmable PLL clock source which may be used as a sample clock for the A/D input channels.

```
Module.Trigger(PmcModule::tOutput, false);
```

The code above states that the output trigger is in a inactive state.

```
FBlockCount = 0;
FBlockRate = 0;
FTriggered = -1;
TestCounter = 0;
Time.Reset();
```

The class variables above are used to maintain counts of blocks received, reception rate and whether the module is currently triggered. These values are initialized prior to each streaming run. The Time.Reset() is to clear any pass data rate calculations.

```
PrefillCount = std::max(Settings.PrefillPeriod, 1);
```

The above code extract the prefill count in seconds up to one second. This variable will be used to prevent any instantaneous uderflow caused by the DACs wanting data. The prefill count will be used to prefill the bus-master region.

```
Module.Dio().DioPortConfig(Settings.DioConfig);
Module.FrontPanel().FrontPanelPortConfig(Settings.FrontPanelConfig);
```

The module supports programmable bit I/O, available on connector JP16 and on the Front Panel connector. The code fragment above programs the direction of these DIO bits in accordance with the settings from the GUI.

```
//
//  Channel Enables
Module.Input().Info().Channels().DisableAll();
Module.Output().Info().Channels().DisableAll();
for (int i = 0; i < Channels(); ++i)
    if ((Settings.ActiveChannels[i] ? true : false))
        Module.Output().Info().Channels().Enabled(i, true);

int ActiveChannels = Module.Output().Info().Channels().ActiveChannels();
if (!ActiveChannels)
    {
    Log("Error: Must enable at least one channel");
    UI->AfterStreamStop();
    return false;
    }
```

Disable input channels (since this is DAC example), and enable output channels. fragment above programs the direction of these DIO bits in accordance with the settings from the GUI.

```
FStreaming = true;
```

```
// Set Decimation Factor
int factor = Settings.DecimationEnable ? Settings.DecimationFactor : 0;
Module.Output().Decimation(factor);
```

Sample clocks will be affected by the decimation factor used. All data will be played by the DAC(s), but at a slower rate if decimation is enabled.

```
// All channels trigger together
Module.Output().ExternalTrigger((Settings.ExternalTrigger == 1));
// Frame count in units of packet elements
if (Settings.Framed)
    Module.Output().Framed(Settings.FrameCount);
else
    Module.Output().Unframed();
```

Samples will not be played until the channels are triggered. Triggering may be initiated by a software command or via an external input signal to the Trigger SMA connector. The code fragment above selects the trigger mode.

```
enum IUsesX3Alerts::AlertType Alert[] =
     {
     IUsesX3Alerts::alertTimeStampRollover,
     IUsesX3Alerts::alertSoftware,
     IUsesX3Alerts::alertWarningTemperature,
     IUsesX3Alerts::alertPllLost,
     IUsesX3Alerts::alertOutputFifoUnderrun,
     IUsesX3Alerts::alertOutputTrigger
     };

for (unsigned int i = 0; i < Settings.AlertEnable.size(); ++i)
    Module.Alerts().AlertEnable(Alert[i], Settings.AlertEnable[i] ? true : false);
```

The fragment above enables alert generation by the module. The GUI control includes check boxes for each of the types of alerts of which the module is capable. The enabled state of the check boxes is copied into the Settings.AlertEnable array. This code fragment applies the state of each bit in that array to the Alerts() sub-object within the module. During streaming, an alert message will be sent to the Host tagged with a special alert packet ID (PID), to signify the alert condition.

```
// Calculate waveform buffer
ShortDG Packet_DG(WaveformPacket);
//
// Calculate Packet Size in shorts
int packet_size_shorts = Settings.StreamPacketSize*ActiveChannels;
while ((packet_size_shorts%4)!=0)
    packet_size_shorts += ActiveChannels;

Packet_DG.Resize(packet_size_shorts);

PacketBufferHeader PktBufferHdr(WaveformPacket);
PktBufferHdr.PacketSize(Settings.StreamPacketSize);
PktBufferHdr.PeripheralId(Module.Output().PacketId());
PktBufferHdr[1] = HeaderTagValueOriginal;
```

The buffer size is calculated in terms of samples per active channel based on the packet size specified in th GUI, so for example is 1000 is the Packet size in the GUI and two channels are enabled, then the short buffer (16-bit word) will be of size 2000. In this example w chose a ShortBuffer since all X3 modules (up to date) have 16-bit DACs.
The PeripheralId for DAC = 0x02.

```
//
//  Builds waveform buffer
```

```
        BuildWave(WaveformPacket, Settings.WaveType);

        //  Start Streaming
        Stream.Start();
```

The Stream.Start command applies all of the above configuration settings to the module, then enables PCI data flow. However, samples will not be played until the module is triggered.

```
        Log("Stream Mode started");
        UI->Status("Stream Mode started");

        FTicks = 0;

        return true;
    }
```

Handle Data Required

Once streaming is enabled and the module is triggered, data flow will commence. Samples will be bus-mastered into the Module's FIFO and sent to the proper DAC. The Buffer header is used by the Module's logic as a steering mechanism. Note, however, that this event is signaled from within a background thread, so, you must not perform non-reentrant OS system calls (such as GUI updates) from within your handler unless you marshal said processing into the foreground thread context.

```
    //---------------------------------------------------------------------------
    // ApplicationIo::HandleDataRequired()
    //---------------------------------------------------------------------------

    void ApplicationIo::HandleDataRequired(PacketStreamDataEvent & Event)
    {
        SendOneBlock(Event.Sender);
    }

    //------------------------------------------------------------------------------
    // ApplicationIo::SendOneBlock()
    //------------------------------------------------------------------------------

    void ApplicationIo::SendOneBlock(PacketStream * PS)
    {
        ShortDG Packet_DG(WaveformPacket);

        // Calculate transfer rate in kB/s
        double Period = Time.Differential();
        if (Period)
            FBlockRate = Packet_DG.SizeInBytes() / (Period*1.0e3);

        //
        //  No matter what channels are enabled, we have one packet type
        //    to send here
        PS->Send(WaveformPacket);

        ++FBlockCount;
    }
```

HandleDataRequired() will be called when a buffer is needed, here we show that we will play a pre-filled buffer at callback time (every module interrupt).

EEProm Access

Each PMC module contains an IDROM region that can be used to write information associated with the module. In the next line of code we make a call to Malibu method IdRom(), which returns an object that acts as interface to that region. The following methods illustrate how to write and read information from IDROM. StoreToRom() and ReadRom() are the two IdRom methods used to save and retrieve data to/from memory.

```
//---------------------------------------------------------------------------
//  ApplicationIo::WriteRom() --  Write rom using relevant settings
//---------------------------------------------------------------------------

void ApplicationIo::WriteRom()
{
    Module.IdRom().Name(Settings.ModuleName);
    Module.IdRom().Revision(Settings.ModuleRevision);
        for (int ch = 0; ch < Channels(); ++ch)
        {
        Module.Output().Gain(ch, Settings.DacGain[ch]);
        Module.Output().Offset(ch, Settings.DacOffset[ch]);
        }

    Module.Output().Calibrated(Settings.Calibrated);
    Module.IdRom().StoreToRom();
}

//---------------------------------------------------------------------------
//  ApplicationIo::ReadRom() --  Read rom and update relevant settings
//---------------------------------------------------------------------------

void ApplicationIo::ReadRom()
{
    Module.IdRom().LoadFromRom();

    Settings.ModuleName = Module.IdRom().Name();
    Settings.ModuleRevision = Module.IdRom().Revision();

    for (int ch = 0; ch < Channels(); ++ch)
        {
        Settings.DacGain[ch] = Module.Output().Gain(ch);
        Settings.DacOffset[ch] = Module.Output().Offset(ch);
        }
    Settings.Calibrated = Module.Output().Calibrated();
}
```

A one-second timer handler is used to calculate data rates and provide status on Digital I/O, temperature, etc. It is also to fire the very first trigger. If the module is configured for Framed Mode, then only one frame will be played. If the module is configured to run in Un-Framed Mode, then one trigger is sufficient until the module is instructed to stop streaming.

```
//---------------------------------------------------------------------------
//  ApplicationIo::HandleTimer() --  Per-second status timer event
//---------------------------------------------------------------------------

void ApplicationIo::HandleTimer(OpenWire::NotifyEvent & Event)
{
    int DigIn = DioData();
    int FrontIn = FrontPanelData();

    // Display status
    UI->PeriodicStatus();
```

```
        FrontPanelData(~FrontIn);
        DioData(~DigIn);

        // Initial trigger state machine below
        if (IsTriggered() || !Settings.AutoTrigger)
            return;

        if (PrefillCount)
            --PrefillCount;

        if ((Settings.ExternalTrigger == 0) && (PrefillCount == 0))
            SoftwareTrigger();
    }
```

Developing Host Applications

Developing an application will more than likely involve using an integrated development environment (IDE) , also known as an integrated design environment or an integrated debugging environment. This is a type of computer software that assists computer programmers in developing software.

The following sections will aid in the initial set-up of these applications in describing what needs to be set in Project Options or Project Properties.

Borland Turbo C++

BCB10 (Borland Turbo C++) Project Settings

When creating a new application with File, New, VCL Forms Application - C++ Builder

Change the Project Options for the Compiler:

Project Options
  ++ Compiler (bcc32)
    C++ Compatibility
      Check 'zero-length empty base class (-Ve)'
      Check 'zero-length empty class member functions (-Vx)'

In our example Host Applications, if not checked an access violation will occur when attempting to enter any event function.

i.e.
    Access Violation OnLoadMsg.Execute – Load Message Event
Because of statement
    Board->OnLoadMsg.SetEvent(this, &ApplicationIo::DoLoadMsg);

Change the Project Options for the Linker:

Project Options
  Linker (ilink32)
    Linking – **uncheck 'Use Dynamic RTL'**

In our example Host Applications, if not unchecked, this will cause the execution to fail before the Form is constructed.

Error: First chance exception at $xxxxxxxx. Exception class EAccessViolation with message "Access Violation!"
Process ???.exe (nnnn)

Other considerations:

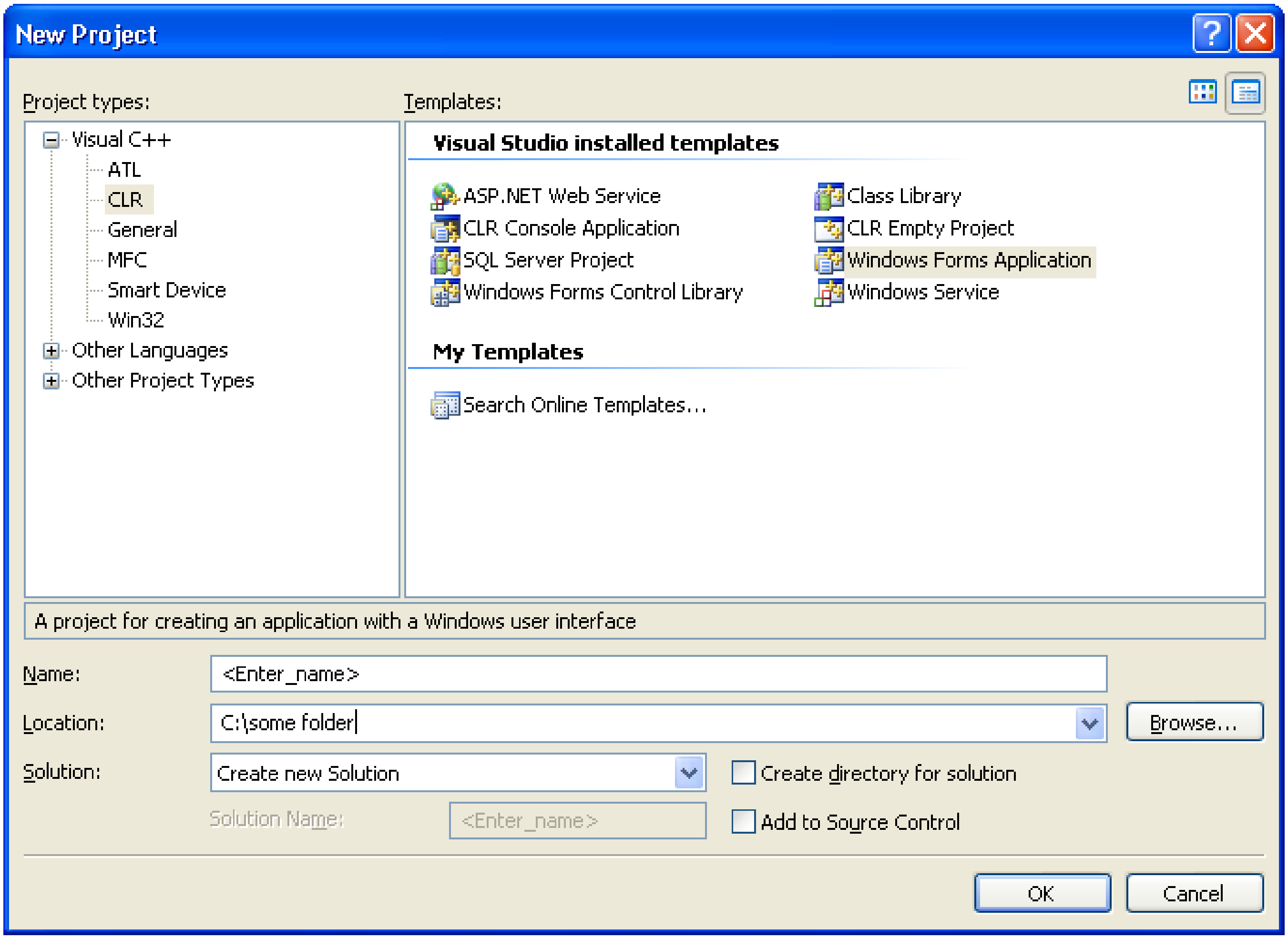
- Project Options
  - ++ Compiler (bcc32)
    - Output Settings
      - **check – Specify output directory for object files(-n)**
        - **(release build) Release**
        - **(debug build) Debug**
    - Paths and Defines
      - **add Malibu**
    - Pre-compiled headers
      - **uncheck everything**
  - Linker (ilink32)
    - Output Settings
      - **check – Final output directory**
        - **(release build) Release**
        - **(debug build) Debug**
    - Paths and Defines
      - (ensure that Build Configuration is set to All Configurations)
      - **add Lib/Bcb10**
      - (change Build Configuration to Release Build)
      - **add lib\bcb10\release**
      - (change Build Configuration to Debug Build)
      - **add lib\bcb10\debug**
      - (change Build Configuration back to All Configurations)

  - Packages
    - **uncheck - Build with runtime packages**

Microsoft Visual Studio 2005

Microsoft Visual C++ 2005 (version 8) Project Properties

When creating a new application with File, New, Project with Widows Forms Application:



New Project

Project types:

- Visual C++
  - ATL
  - CLR
  - General
  - MFC
  - Smart Device
  - Win32
- Other Languages
- Other Project Types

Templates:

Visual Studio installed templates

ASP.NET Web Service	Class Library
CLR Console Application	CLR Empty Project
SQL Server Project	Windows Forms Application
Windows Forms Control Library	Windows Service

My Templates

Search Online Templates...

A project for creating an application with a Windows user interface

Name: <Enter_name>

Location: C:\some folder

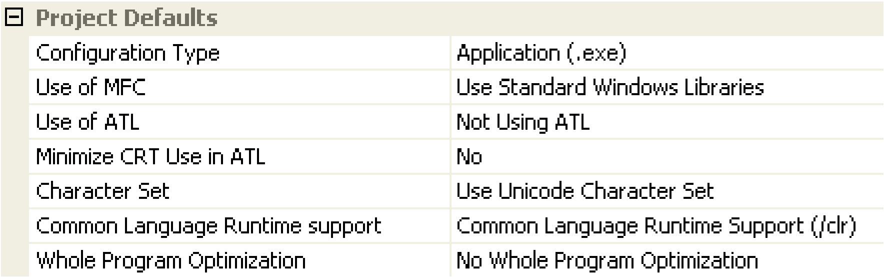
Solution: Create new Solution

Solution Name: <Enter_name>

□ Create directory for solution

□ Add to Source Control

Project Properties (Alt+F7)
Configuration Properties



Project Defaults	
Configuration Type	Application (.exe)
Use of MFC	Use Standard Windows Libraries
Use of ATL	Not Using ATL
Minimize CRT Use in ATL	No
Character Set	Use Unicode Character Set
Common Language Runtime support	Common Language Runtime Support (/clr)
Whole Program Optimization	No Whole Program Optimization

C++
General
Additional Include Directories

Malibu
PlotLab/Include – for graph/scope display

Code Generation
Run Time Library

Multi-threaded Debug DLL (/Mdd)

Precompiled Headers
Create/Use Precompile Headers

Not Using Precompiled Headers

Linker
Additional Library Directories

Innovative\Lib\Vc8

If anything appears to be missing, view any of the example sample code Vc8 projects.

DialogBlocks

DialogBLocks Project Settings (under Linux)

```
Project Options
[Configurations]
Compiler name = GCC
Build mode = Debug
Unicode mode = ANSI
Shared mode = Static
Modularity = Modular
GUI mode = GUI
Toolkit = <your choice wxX11, wxGTK+2, etc>
Runtime linking = Static or Dynamic, we use Static to facilitate execution of programs out of the box.
Use exceptions = Yes
Use ODBC = No
Use OpenGL = No
Use wx-config = Yes
Use insalled wxWidgets = Yes
Enable universal binaries = No
...
Debug flags = -ggdb -DLINUX
Library path = %INNOVATIVE%/Lib/Gcc/Debug, %WINDRIVER%/lib
Linker flags = %AUTO% -Wl, @%PROJECTDIR%/Example.lcf
IncludePath= -I%INNOVATIVE%/Malibu -I%INNOVATIVE%/Malibu/LinuxSupport %AUTO%

[Paths]
INNOVATIVE= /usr/Innovative
WINDRIVER= /usr/Innovative/WinDriver
WXWIN= /usr/wxWidgets-2.8-7      provided that this is the location where you have installed wxWidgets.
```

Summary

Developing Host and target applications utilizing Innovative DSP products is straightforward when armed with the appropriate development tools and information.

Applets

The software release for a baseboard contains programs in addition to the example projects. These are collectively called “applets”. They provide a variety of services ranging from post analysis of acquired data to loading programs and logic to a full replacement host user interface. The applets provided with this release are described in this chapter.

Shortcuts to these utilities are installed in Windows by the installation. To invoke any of these utilities, go to the Start Menu | Programs | <<Baseboard Name>> and double-click the shortcut for the program you are interested in running.

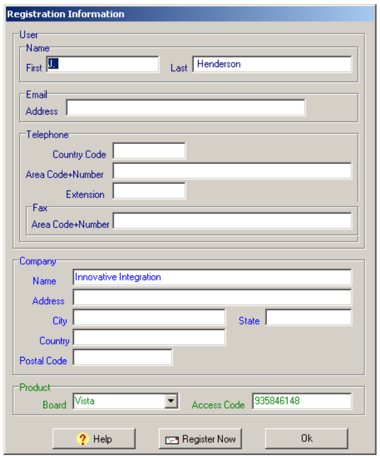
Common Applets

Registration Utility (NewUser.exe)

Some of the Host applets provided in the Developers Package are keyed to allow Innovative to obtain end-user contact information. These utilities allow unrestricted use during a 20 day trial period, after which you are required to register your package with Innovative. After, the trial period operation will be disallowed until the unlock code provided as part of the registration is entered into the applet. After using the NewUser.exe applet to provide Innovative Integration with your registration information, you will receive:

The unlock code necessary for unrestricted use of the Host applets

A WSC (tech-support service code) enabling free software maintenance downloads of development kit software and telephone technical hot line support for a one year period.

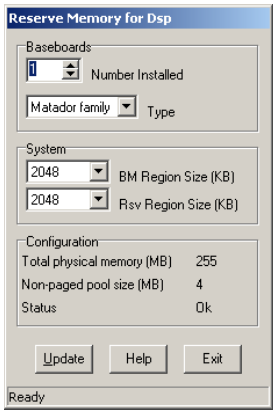


Name: First J. Last Henderson

Company Name: Innovative Integration

Product Board: Vista Access Code: 935846148

Reserve Memory Applet (ReserveMemDsp.exe)



Baseboards
1 Number Installed
Matador family Type

System
2048 BM Region Size (KB)
2048 Rsv Region Size (KB)

Configuration
Total physical memory (MB) 255
Non-paged pool size (MB) 4
Status Ok

Ready

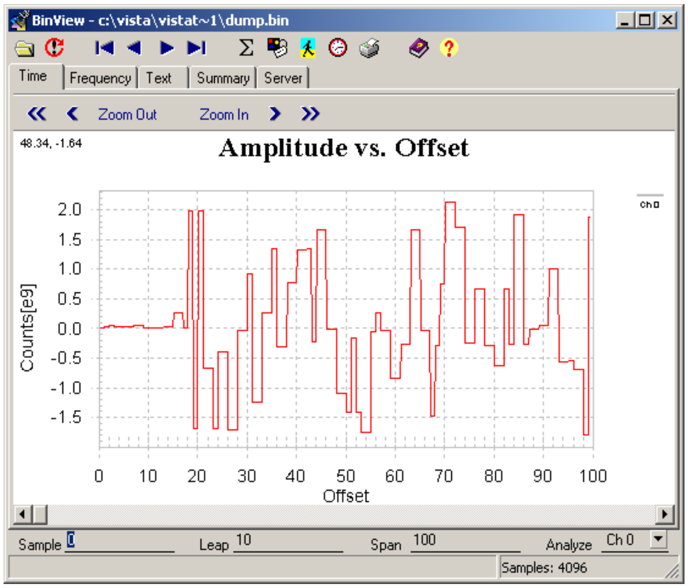
Each Innovative PCI-based DSP baseboard requires 2 to 8 MB of memory to be reserved for its use, depending on the rates of bus-master transfer traffic which each baseboard will generate. Applications operating at transfer rates in excess of 20 MB/sec should reserve additional, contiguous busmaster memory to ensure gap-free data acquisition.

To reserve this memory, the registry must be updated using the ReserveMemDsp applet. If at any time you change the number of or rearrange the baseboards in your system, then you must invoke this applet to reserve the proper space for the busmaster region. See the Help file ReserveMemDsp.hlp, for operational details.

Data Analysis Applets

Binary File Viewer Utility (BinView.exe)

BinView is a data display tool specifically designed to allow simplified viewing of binary data stored in data files or a resident in shared DSP memory. Please see the on-line BinView help file in your Binview installation directory.



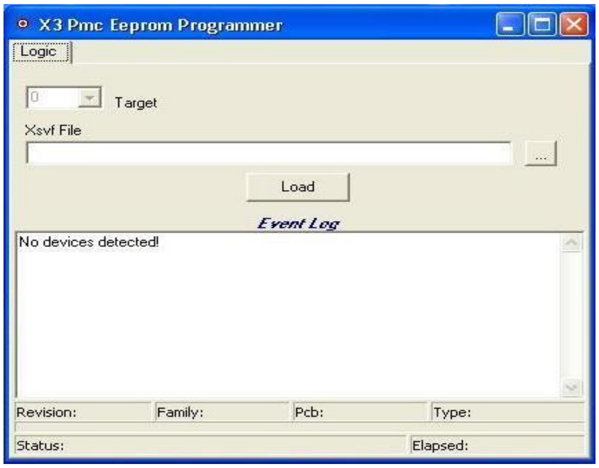
Sample 0 Leap 10 Span 100 Analyze Ch 0

Samples: 4096

Applets for the X3 Modules

EEProm

X3-Servo has two logic devices on it. One controls the analog hardware. This logic can be modified by the user, and must be loaded by the user with an image on each session. The second device performs the baseboard enumeration and PCI interface and has a ROM so that it can function at power up. The EEProm applet is designed to allow field-upgrades of this PCI logic firmware on the X3-Servo. The utility permits an embedded firmware logic update file to reprogrammed into the module Flash ROM, which stores the "personality" of the board. Complete functionality is supplied in the application’s help file.



No devices detected!

Finder

The Finder is designed to help correlate board target numbers against PCI slot numbers in systems employing multiple boards.

Target Number

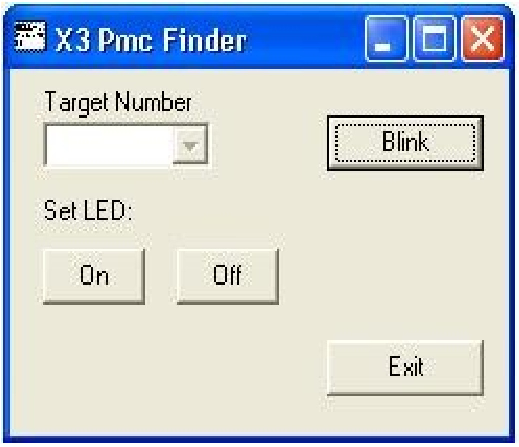
Select the Target number of the board you wish to identify using the Target Number combo box.

Blink

Click the Blink button to blink the LED on the board for the specified target. It will continue blinking until you click Stop.

On/OFF

Use the On and Off buttons to activate or deactivate (respectively) the LED on the baseboard for the specified target. When you exit the application, the board’s LED will remain in the state programmed by this applet.

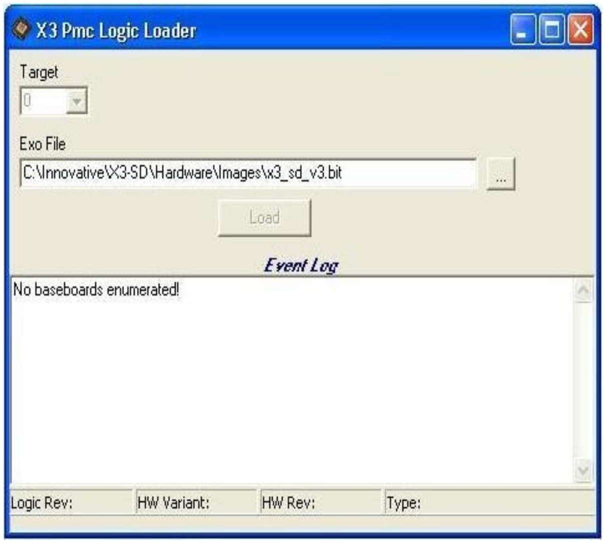


Logic Loader

The logic loader applet is used to deliver known-operational logic images to the user logic device installed on a X3-Servo. The user logic must be loaded once per session, as the logic part is cleared on bus reset or power up.

The utility may be used to configure the firmware either through its command line interface or from its GUI Windows user interface. The former is often convenient during PC boot-up to install a standard logic file. Place a short cut with the command line option set into the Windows Startup folder to execute the program when the system is started.

This application supports configuration of the onboard Spartan 3 logic device from a .bit file produced by popular logic design tools (including Xilinx's). It is essential that the Spartan 3 be programmed before using related applications, since some of the baseboard peripherals are dependent on the personality of the configured logic.



Target: 0

Exo File: C:\Innovative\X3-SD\Hardware\Images\x3_sd_v3.bit

No baseboards enumerated!

Logic Rev: | HW Variant: | HW Rev: | Type:

X3-Servo Hardware

Introduction

The X3-Servo is a member of the X3 XMC family that has 12 channels of 16-bit, 250 kSPS A/D conversion and 12 channels of 16-bit, 2 MSPS DAC and front panel digital IO. The A/D and DAC devices have low latency to support servo applications. The front panel DIO is useful for controls and sensing inputs.

A high performance computing core for signal processing, data buffering and system IO is built around a Spartan3A DSP 1.8M gate FPGA (optional 3.4M). Supporting peripherals include 2MB of SRAM, conversion timebase and triggering circuitry, 44 bits digital IO, and a PCI Express interface. The module format is a single slot XMC conforming to IEEE 1384 CMC standard and is compatible with XMC.3 host sites.

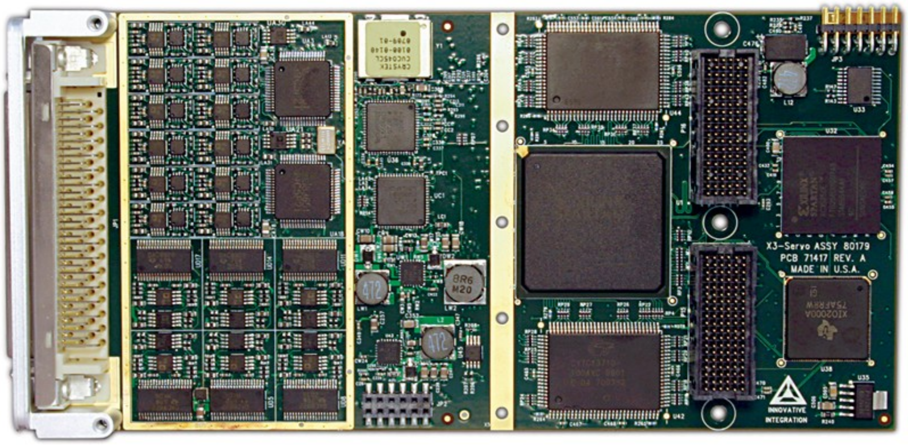


Figure 11. X3-Servo Module (with analog shield removed)

Custom application logic development for the X3-Servo is supported by the FrameWork Logic system from Innovative using VHDL and/or MATLAB Simulink. Signal processing, data analysis, and application-specific algorithms may be developed for use in the X3-Servo logic and integrated with the hardware using the FrameWork Logic.

Software support for the module includes host integration support including device drivers, XMC control and data flow and support applets.

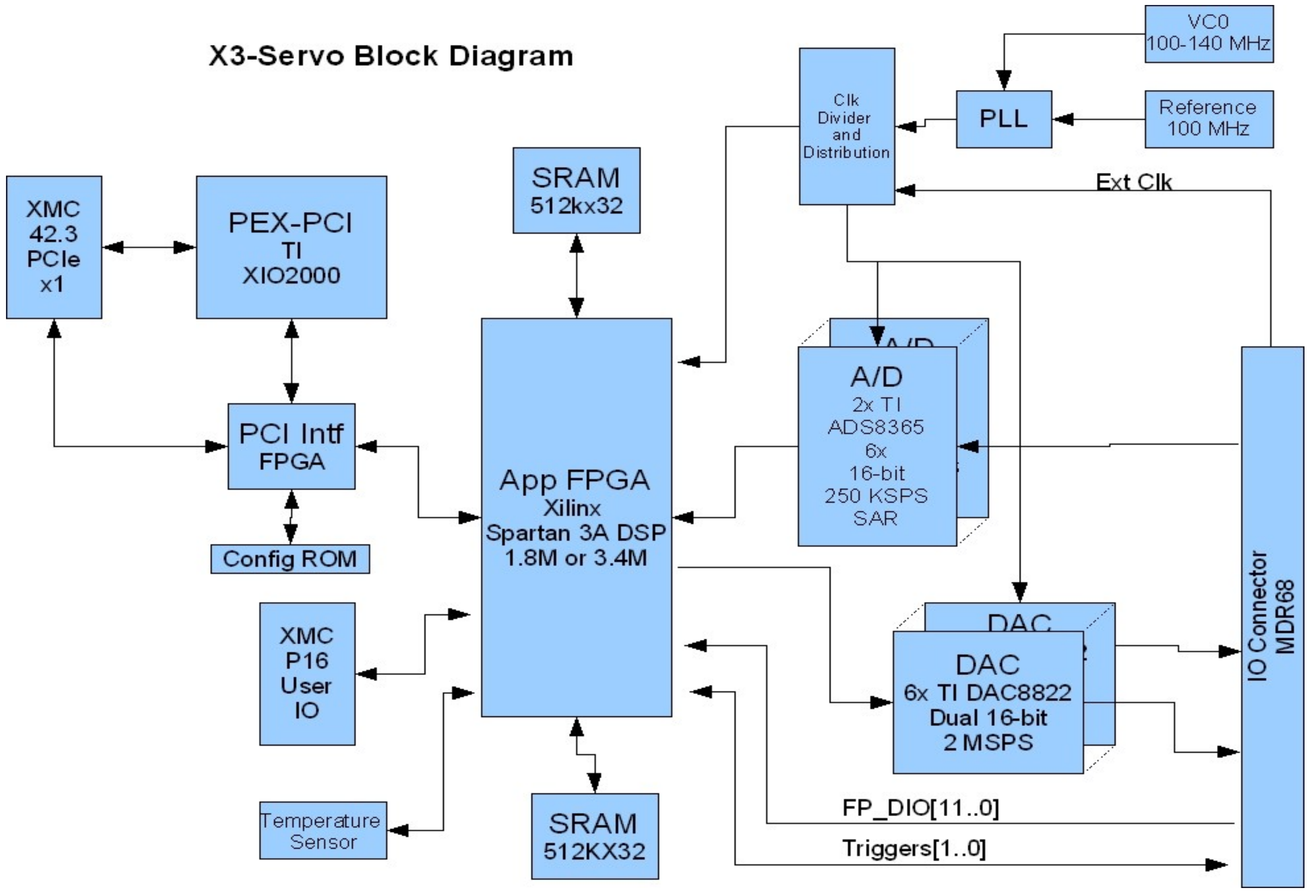


Figure 12. X3-Servo Block Diagram

A/D Conversion Features

A/D Converters

The X3-Servo has 12 channels of 16-bit A/D sampling at up to 250 KSPS using Texas Instruments ADS8365 A/Ds. The ADS8365 has six A/D channels that convert simultaneously. The inputs are not multiplexed and all six channels can convert simultaneously. The ADS8365 is a successive approximation converter (SAR) that has low data latency regardless of sample rate.

Feature	Description
Inputs	12, independent
Input Range	+10V to -10V, differential (full scale is 20Vp-p)
Input Impedance	>1M ohm || 15 pF (excludes cable)
A/D Devices	Texas Instruments ADS8365
Output Format	2's complement, 16-bit
Number of A/D Devices	12 simultaneously sampling
Sample Rate	DC-250 kSPS
Sample Clock Rates from PLL	97 kHz to140 MHz
Calibration	Factory calibrated for gain and offset errors. Non-volatile EEPROM coefficient memory.

Table 14. X3-Servo A/D Features

Conversion clocking is provided through separate, special circuitry that minimizes jitter on the clocks. The clock circuitry allows for a variety of clock sources, including two external sources, to be used as conversion timebases. See the clock discussion for more details.

The following block diagram shows the general arrangement of the A/D. The differential inputs, from the front panel connector, are adjusted for range through a differential amplifier and input to the A/D.

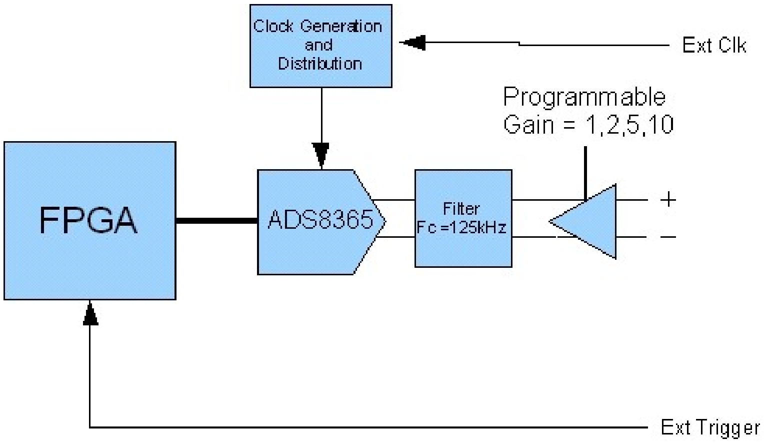

Clock Generation and Distribution
Ext Clk
Programmable Gain = 1,2,5,10
FPGA
ADS8365
Filter Fc =125kHz
+
–
Ext Trigger

Figure 13. X3-Servo A/D Channel Diagram

Input Range and Conversion Codes

The A/D conversion codes for the analog ranges are shown in the following table. All voltages are differential- meaning that +10V requires that the voltage difference between inputs is +10V.

The output codes are 2's complement, 16-bit numbers.

	G=1	G=2	G=5	G=10	Nominal Conversion Code (hex)
Differential Input Voltage	+10V	+5V	+2V	+1V	0x7FFF
	+5V	+2.5V	+1V	500 mV	0x4000
	0V	0V	0V	0V	0x0000
	-5V	-2.5V	-1V	-500 mV	0xA000
	-10V	-5V	-2V	-1V	0x8000

Table 15. A/D Conversion Coding

Driving the A/D Inputs

The X3-Servo has fully differential inputs with >1M input impedance. The input range is specified as a differential voltage for the V+ and V- input with a common mode voltage of 0V for full range. A full scale input is 5Vp-p on EACH of the inputs for a gain of 1, or one leg grounded and a 20Vp-p input on the other (-10V to +10V).

The input signals should be driven differentially to realize the full performance of the A/D. The differential inputs reject common mode noise from the system and the card itself to improve the conversion results. If you drive the inputs single-ended, the results will be worse by at least 6dB in most cases, worse if the system noise is high.

For signal ended use, the unused input **must** be grounded. Input voltage range is limited to +10V to -10V for single-ended use for the standard configuration.

The driving signal must also sink the input bias current from the front end amplifier. For DC coupled inputs, this is usually not a problem since this current is less than 50 nA which is easily sunk/sourced by the driving device. For AC-coupled inputs, a 100K or less resistor to ground is recommended.

A/D Filter Characteristics

The A/D channels have an anti-alias filter to suppress high frequency noise. This filter is a single-pole set to 400 kHz. This value was chosen because it provides high frequency rejection and has little effect on input phase response out to 125 kHz (half the A/D sample rate). Test data section shows the filter response.

Overrange Detection

The logic is used to detect overrange conditions on the A/D devices. When a full scale positive (0x7FFF) or negative (0x8000) reading is detected by the logic, an analog overrange is likely to have occurred. Overrange occurs when the input signal is above the +/-10V differential range is exceeded. For small overrange conditions of less than 5% overrange, the A/D will recover in a few samples to proper readings. For larger overrange conditions, the A/D may require longer to recover.

The A/D overrange detection in the logic be used to trigger an alert in the logic to notify the application when this error condition has occurred. The alert message shows when the overrange occurred in system time and which channels overranged.

Custom logic has access to the overrange bits in the A/D interface component. Each data sample indicates when an overrange occurs as part of its status byte appended to the data. This allows implementation of automatic gain controls for auto-ranging external front end signal conditioning.

A/D Sampling Rates

The ADS8365 supports sample rates from DC to 250 KSPS on the X3-Servo module. The sample clock can be either an external clock input or generated on the card by a PLL. A full description of the sample clocks is described in the sample rate generation section of this manual.

When the PLL is used, the sample clock has a minimum rate of 97.656 kHz. Sample rates lower than 97.656 kHz are supported using decimation in the logic. The FrameWork logic supports 1:N decimation to which means that 1 point is kept for every N collected. All channels must be decimated at the same rate when this mode is used in the standard logic. Data latency is not affected by sample rate because the A/D is an SAR architecture.

Supporting software functions in the Malibu library are used to configure the sample clock mode and decimation to achieve the desired sample rate. Since the PLL configuration is somewhat complex, it is recommended that these functions be used for most applications.

D/A Conversion Features

D/A Converters

The X3-Servo has 12 channels of 16-bit D/A conversion at up to 1.5 MSPS consisting of six Texas Instruments DAC8822 DACs. The DAC8822 is a dual channel device and is configured to update the two outputs simultaneously; all 12 channels update simultaneously. The DAC8822 device has low data latency for conversion regardless of sample rate.

Feature	Description
Outputs	12, independent
Output Range	+10V to -10V
Output Drive Current	10 mA, max
D/A Devices	Texas Instruments DAC8822
Output Format	2's complement, 16-bit
Number of DAC Devices	12 simultaneously updated
Updated Rate	DC-1500 kSPS** ** Limited to 1500 kSPS using standard logic. Devices support up to 2000 kSPS.
Sample Clock Rates from PLL	97 kHz to140 MHz
Calibration	Factory calibrated for gain and offset errors. Non-volatile EEPROM coefficient memory.

Table 16. X3-Servo DAC Features

Conversion clocking is provided through separate, special circuitry that minimizes jitter on the clocks. The clock circuitry allows for a variety of clock sources, including two external sources, to be used as conversion timebases. See the clock discussion for more details.

The following block diagram shows the general arrangement of the DAC. The DACs are directly connected to the FPGA , which provides low latency for the output data path and provides direct control of the devices for custom logic designs. The analog circuitry for the DAC output converts from the DAC output current to voltage range of -10 to +10V on the connector, with reconstruction filtering. Special output voltage ranges can be ordered to meet application requirements.

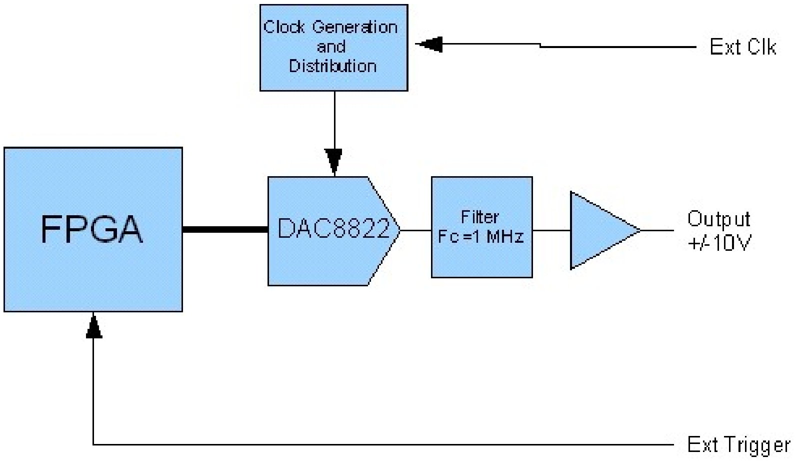


Figure 14. X3-Servo DAC Channel Diagram

Output Range and Conversion Codes

The DAC conversion codes for the output voltages are shown in the following table.

The output codes are 2's complement, 16-bit numbers.

Output Voltage	Nominal Conversion Code (hex)
+10V	0x8000
+5V	0xC000
0V	0x0000
-5V	0x4000
-10V	0x7FFF

Table 17. DAC Conversion Coding

DAC Outputs

The X3-Servo DAC outputs are single-ended voltage outputs with <1 ohm output impedance. The output voltage is referenced to the card ground.

Each DAC channel has a reconstruction filter on its output. The filter reduces higher frequencies in the DAC outputs due to the DAC switching.

Test data section shows the filter response.

The DAC outputs are driven by an op-amp capable of +/-10 mA drive current. This is sufficient for most applications. If more drive current is required, a power amplifier should be added to the system.

The DAC outputs should be carefully handled in the output cabling. Each DAC output has a ground pin adjacent to it on the connector, and in most cases this ground should be used as the return path for that output.

DAC Sample Underrun

An underrun occurs when a DAC update is required but no new data is available. This can occur if the application cannot keep up with the update rate. An underrun can be caused by conditions such as the host being too busy to provide data in a timely fashion or a logic design that cannot meet the required servo loop rate.

When an underrun occurs, the last point provided to the DAC is simply repeated. For waveform generation, this means that the output has a duplicated point. For servo controls, this creates a one sample delay in the output update. Repeated underrun conditions result in large data latency and eventually the DAC FIFO overflowing. If an underrun occurs, it will occur on all channels since the channels are updated as a group.

The logic detects data underrun conditions to the DAC devices and can provide a warning of this condition. The underrun is used to trigger an alert in the logic that notifies the application when this error condition has occurred. The alert message shows when the underrun occurred in system time.

DAC Update Rates

The DAC8822 supports update rates from DC to 1.5 MSPS on the X3-Servo module. The update clock can be either an external clock input or generated on the card by a PLL. A full description of the sample clocks is described in the sample rate generation section of this manual.

When the PLL is used, the update clock has a minimum rate of 97.656 kHz. Update rates lower than 97.656 kHz are supported using clock decimation in the logic. The FrameWork logic supports 1:N decimation to which means that 1 output update is performed for every N update clocks. All channels must be decimated at the same rate when this mode is used in the standard logic. Latency for the DAC updated is not affected by sample rate.

Supporting software functions in the Malibu library are used to configure the sample clock mode and decimation to achieve the desired sample rate. Since the PLL configuration is somewhat complex, it is recommended that these functions be used for most applications.

Sample Rate Generation and Clocking Controls

The X3-Servo can use a sample clock from the PLL, the PLL locked to an external clock, or an external clock. This allows the module to synchronize to a system clock or use software programmable sample rates. All clock selections are software programmable on the module.

Clock Mode	Use for	Restrictions	Benefits
PLL with internal reference	Software programmable clock	Clock rate has tuning resolution of about 10 Hz	Low jitter clock
PLL with external reference	Software programmable clock referenced to external clock input	External reference must be 1 to 100 MHz, 50-50 duty cycle, see electrical requirements below	Lock to an external clock and generate an sample clock locked to it; Clean up external clock jitter using the PLL
External Clock	Synchronize sampling to system devices	External clock must be 1 to 100MHz, 50-50 duty cycle, low jitter	Sample according to an external clock

Table 18. Sample Clock Modes

The PLL can generate many sample rates that suit most applications. The advantage of using the PLL is that the sample clock is very clean and low jitter. The output frequency of the PLL is programmable and is determined by the reference clock rate and the VCO tuning range.

Software functions for PLL configuration, monitoring and clock distribution are provided in Innovative's Malibu software toolkit that configure the operating mode and sample rate required for the desired sample data rate.

The X3-Servo uses two AD9510 devices: the first device can use the PLL, while the second is used for divider and distribution function only. This provides a sample clock generation range from 97.656 kHz to 140 MHz. The useful range for the A/Ds is limited to 250 kHz and to 2 MHz for the DACs (1 MHz with standard logic).

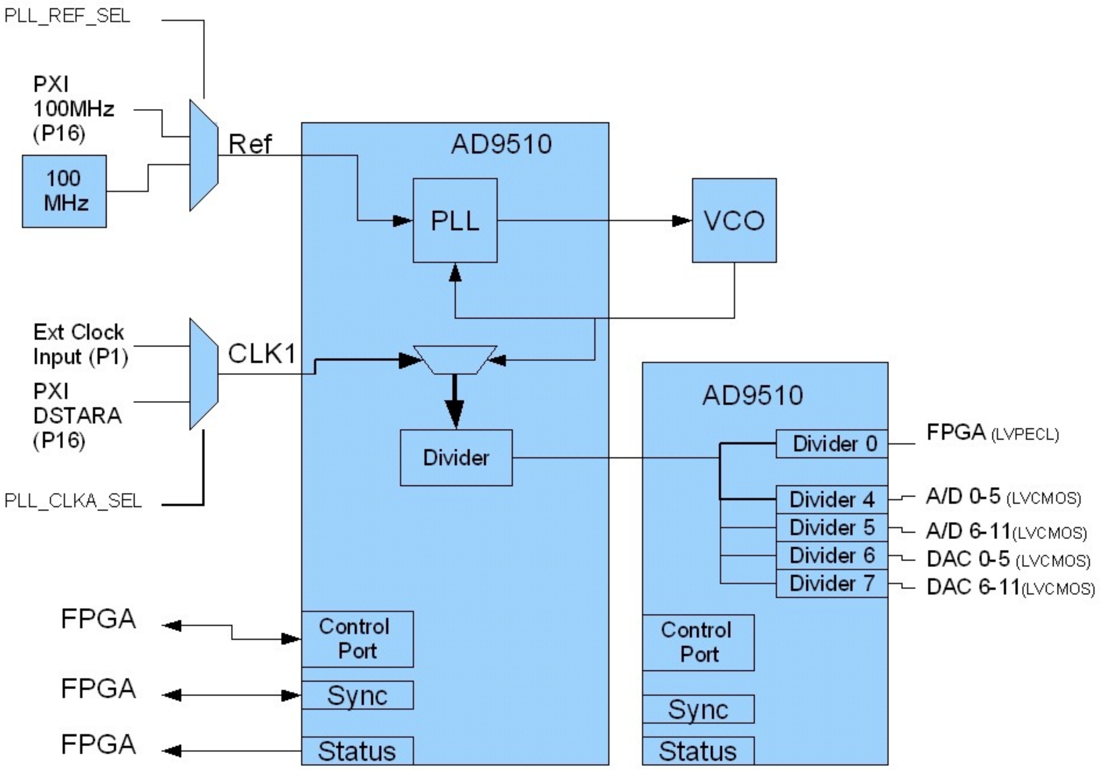


Figure 1. X3-Servo Clock Generation and Controls Block Diagram

The PLL reference is either a fixed 100 MHz reference clock or an external reference clock. The output of the PLL is synchronous to the reference clock and the reference clock input, or integer division of the reference, determines the tuning resolution of the PLL. To achieve an exact frequency that is not a division of the reference clock, it is necessary to supply an external reference. The PLL will generate an output synchronous to the external reference.

The sample clock for the front panel DIO is direct from the clock distribution circuitry and is NOT derived from the application logic clocks or PCI Express bus clock. This is because these clocks have more jitter (phase noise) .

Note: Conversion clocking is separate from triggering – sample clock is the time when samples are digitized, but trigger determines when those samples are kept.

External Clock and Reference Inputs

The X3-Servo has two external inputs that that may be used as sample clock plus two external inputs that may be used as the PLL reference clock. The two external input clocks, *Ext_Clk* and *PXI_DSTARA*, can be directly used as the sample clock. The 100 MHz clock oscillator and PXI_100M clock can be used as references to the PLL. The following table shows the clock multiplexer controls for the X3 modules.

Control Signal	Device	Function	Result
PLL_REF_SEL	PLL Reference Mux	Selects either PXI_100M or 100MHz fixed oscillator as the PLL reference	0 = 100 MHz 1 = PXI_100M
PLL_CLKA_SEL	External Clock Mux	Selects either Ext_Clk or PXI_DSTARA as input to the clock distribution	0 = Ext_Clk 1 = PXI_DSTARA

Table 1. X3 External and Reference Clock Selection

To use an external clock, the external clock multiplexer must be configured to select either the front panel external clock or the PXI_DSTARA input on P16. The control signal, PLL_CLKA_SEL is from the application logic FPGA and is set by the host software when the standard logic image is used.

The following diagram shows the clock path when an external clock is used. Note that the PLL is bypassed when using an external clock.

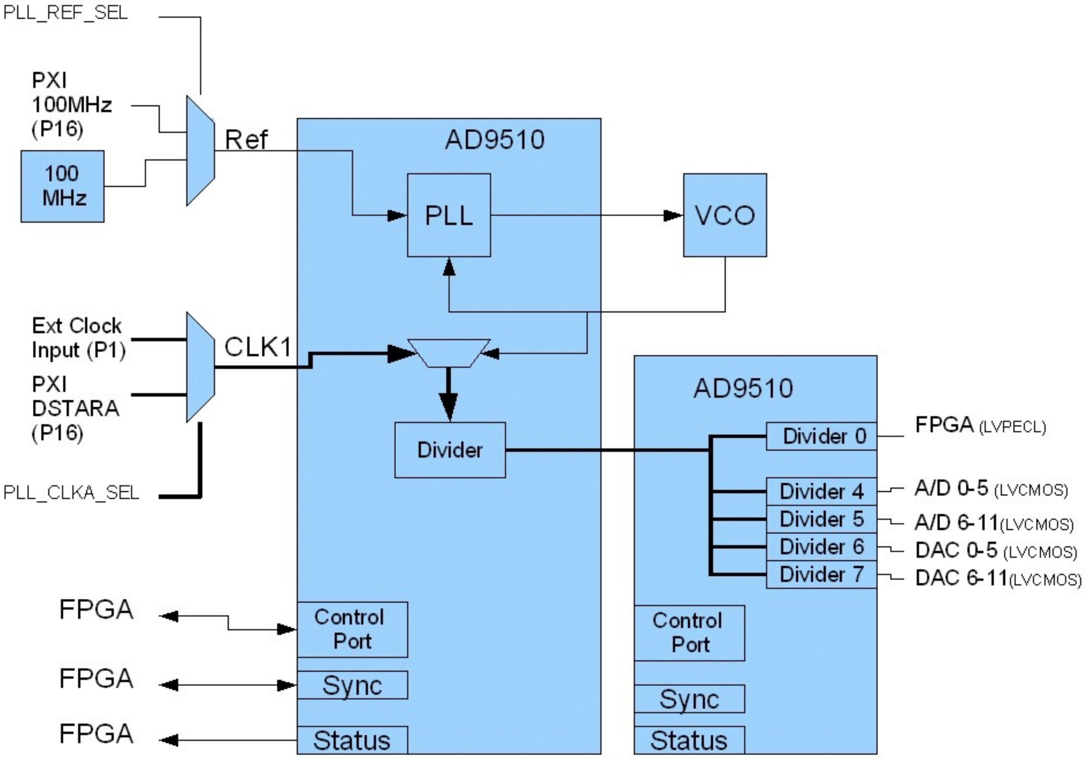


Figure 1. X3-Servo External Clock Path

The selection of the PLL reference clock is also software programmable. The reference clock multiplexer selects the PLL reference clock as either the 100 MHz oscillator or the PXI_100M input on P16. The control signal, PLL_REF_SEL is from the application logic FPGA and is set by the host software when the standard logic image is used.

All external clock and reference inputs are LVDS and must be driven as a differential pair. Each differential pair is 100 ohm terminated. The LVDS inputs **cannot** be driven single-ended – both inputs must be actively driven. Electrical characteristics of the inputs are shown in the following table.

Parameter	Min	Typical	Max
Input Frequency	0		100 MHz
Input Common Mode Input Voltage	0.5V		2.4V
Input Amplitude	0.2		1Vp-p
Input Termination		100 ohms	
Input Capacitance		15 pF	

Table 1. X3 External Clock and Reference Input Requirements

The external clock and reference inputs are from either the front panel connector JP1 or XMC secondary connector P16. To use the P16 connector inputs, the carrier card must support the P16 pinout shown later in this chapter. Here is where the external clock inputs are connected:

Signal	Connector	+ Input	- Input	Comments
External Clock (ext_clk)	JP1	33	67	MDR68 front panel connector
PXI_DSTARA	P16	A9	B9	XMC secondary connector
PXIE_100M	P16	D9	E9	XMC secondary connector

Table 2. External Clock and Reference Signal Pinouts

PLL Output Range and Resolution Limitations

The sample rates that can be generated are limited by the VCO tuning range, the PLL reference frequency, and the PLL tuning parameter limits. For the standard VCO and PLL circuitry, the sample clocks are limited to 100 kHz resolution. There are also “holes” in the sample rate outputs where the PLL cannot make any frequency because of the VCO tuning range and output divisors.

For VCO tuning range of 100 to 140 MHz, and integer output divisors D = 1 to 32 for each device, the allowable output ranges are shown. Maximum divisor is 1024 (32*32).

Output Divisor, D	Lower Limit (MHz)	Upper Limit (MHz)
1	100.000	140.000
128	0.781	1.094
256	0.390	0.547
384	0.260	0.365
448	0.223	0.313
512	0.195	0.273
704	0.142	0.199
1024	0.098	0.137

Table 3. Allowable Sample Clock Output Ranges

Notice that lower limit is 98 kHz that there are holes in the available frequency such as from 137 to 142 kHz where it is impossible for the PLL to make an output sample clock for the standard configuration. If you need a sample clock not in the allowable ranges, then you must either use an external clock or change the VCO. Contact sales for customizing the VCO to your application requirements.

Programming the PLL

For most applications, the Malibu support software configures the PLL according to the desired sample rate. The software configures all PLL registers so that the output frequency is as close as possible to the required sample rate given the constraints of resolution as determined by the tuning parameters and the VCO tuning range.

Note: It is best to use the Malibu drivers for almost all applications and the following discussion is only for users who need to modify the PLL tuning for very unique applications.

The tuning equation for the AD9510 is :

$$\mathbf{F_{vco} = (F_{ref}/R) \times (PB + A)}$$

where Fref = 100 MHz (or external reference frequency)

R = 1 to 16383, integers

B= 3 to 8191, integers; 1 = bypass

A= 0 to 63, integers, used only in dual modulus mode

P= 1,2,3,4,8,16, or 32

and 100 MHz < Fvco < 140 MHz

All PLL tuning parameters R, B, A and P are software programmable through the PLL interface.

Step		

1	Pick a phase detector frequency close to 100 kHz. This matches the PLL configuration on the card.	Fphase_detector ≈ 100kHz

2	Calculate a reference divisor so that the phase detector frequency is close to 100kHz.	Fphase_detector = Fref / R ≈ 100kHz
		R = 1 to 16383
		100 kHz ≤ Fref ≤ 250 MHz
		R= 1000 for on-board reference

3	For an output sample clock Fout, find the output divisor D that keeps the VCO within its tuning range.	Fvco = Fout/D
		D= 1,2,4,6,8,10,12,14,16,18,20,22,24,26,28,30 or 32
		100 MHz ≤ Fvco ≤ 140 MHz

4	Find PLL feedback divisor	M = int (Fvco / Fphase_detector) 1 ≤ M < 262144
5	Find operating mode, fixed modulus or dual modulus and value of A.	A= Fvco mod Fphase_detector If A = 0, then mode should be fixed divide; if A> 0 then dual modulus mode is used
6	Select value of prescaler P based on operating mode and divisor ratio M.	Pick P and B such that M= P*B using smallest values possible. For fixed divide, P = 1, 2, or 3. For dual modulus, P= 2, 4, 8, 16 or 32. B = 3 to 8191, integers; 1 = bypass

7	Check calculations.	Fout = Fvco/D
		Fvco = (PB+A) * Fref / R , 100 MHz ≤ Fvco ≤ 140 MHz

Table 4. Selecting values for PLL Divisors

$$F_{vco} = (F_{ref}/R) \text{ x } (PB + A)$$

Fs (MHz)	D	FVCO	Fref (MHz)	R	M	A	P	B
100	1	100	100	1000	1000	0	1	1000
70.000	2	140	100	1000	700	0	1	700
69.900	2	139.8	100	1000	699	0	1	699
69.700	2	139.4	100	1000	697	0	1	697
51.300	2	102.6	100	1000	513	0	1	513
31.100	4	124.4	100	1000	311	0	1	311
11.000	10	110	100	1000	110	0	1	110
5.100	20	102	100	1000	51	0	1	51
3.300	32	105.6	100	1000	33	0	1	33
3.200	32	102.4	100	1000	32	0	1	32

Table 5. PLL Example Settings

The software tools provide hooks for direct programming of the PLL divisors to override the automatic functions in Malibu. During experimentation, the PLL registers can also be written using Peek/Poke functions or scripts. These functions are supported on the Debug tab in the example applications SNAP and WAVE. Consult the AD9510 register map for details on register formats.

PLL Lock and Status

The PLL has a status pin that can be programmed to show when the PLL is locked or other status information. The software in the SNAP example configures this pin to be digital lock detect. It indicates when the PLL is locked and ready for use. If the PLL lock is false, the PLL is not working properly and may give poor results or inaccurate frequencies. Even when the PLL is unable to lock, it will produce an output so the mere presence of data does not indicate that the PLL is operating at the correct frequency or is stable.

The PLL lock can also generate an alert to the system if an unlock condition occurs. In this mode, when the PLL falls out of lock, as indicated by a falling edge on the PLL status pin an alert message is created showing the time of the unlock and other system information. See the Alert Log section for further information on using Alerts.

PLL Control Interface

There are two AD9510 devices is mapped into the PCI Express memory space. This allows the host to access the PLL control ports for configuration and status. Writes to the PLL interface ports generate a serial data stream to the PLL that is used to configure the PLL.

Device	Function	Address
U36	PLL/clock divider	BAR1 + 0xA
UC1	Clock divider/distribution	BAR1 + 0x9

Table 1. Clock Devices and Addresses

This interface is only for configuration, **accesses should be spaced by the host computer to be at least 2 ms apart**. The Malibu library handles this restriction as part of the function.

The PLL interface uses a 24-bit word to communicate with the PLL that specifies a read or write access, the PLL register address and the data byte to transfer. For reads, the data byte is a don't care. The 24-bit word is as follows.

Bits	Function
31..24	Not Used.
23	R/W; 1 = read PLL.
22..15	X“00”
14..8	PLL register address.
7..0	Data byte (don't care for reads)

Table 1. PLL Interface Word Format

Writes

Writes to the PLL are pokes to register 0xA, located in the system memory at BAR1 + 0xA. The data value is the 32-bit word as described above.

Step	Read/Write	Address	Value	Comments
1	Write	BAR1+0xA	X”00801C12”	Write to PLL register 0x1C value 0x12

Table 2. PLL Read Sequence

Reads

Reads from the PLL require a two step process consisting of first a write to the PLL register specifying a read at an address, followed by a read from the PLL register that returns the value of the PLL register specified by the address in the PLL word. The PLL is read is a single byte.

For reads, the PLL must be written to with a bit 23 as '1' and the address that is to be read, then read from the PLL register. For example, a read to PLL register X”40” would be performed as

Step	Read/Write	Address	Value	Comments
1	Write	BAR1+0xA	X”00804000”	Set up a read from PLL address X”40”
2	Read	BAR1+0xA	X”x01303xx”	See format below

Table 3. PLL Read Sequence

The PLL readback word has the following format. The PLL read must be performed before any additional writes are performed.

Bits	Function
31	PLL Status Pin
30..24	“0000000”
23..8	X“1303”
7..0	Data byte

Table 4. PLL Read Word

Notes About the PLL Configuration

The PLL *must* be initialized through software before it will make a the correct sample clock rate.   This device has many configurations that require programming of a large number of registers prior to use. The X3 support software provides PLL configurations that satisfy most applications and should be used if possible.

For custom configurations, the AD9510 data sheet should be consulted. The X3-Servo requires the clock assignments as show in the following table. The sample clock (fs) in the FPGA clock is connected to AD9510 output 0. The divider should be programmed to use LVPECL output to the FPGA, while the other clocks are CMOS.

Channel	AD9510 Output (device 2)	Signal Type
FPGA	0 +/-	LVPECL
A/D 5..0	4 -	CMOS
A/D 11..6	5-	CMOS
DAC 5..0	6+	CMOS
DAC 11..0	7+	CMOS

Table 5. PLL Output Assignments

The VCO used with the AD9510 has a tuning range of 100 to 140 MHz and is connected to the CLK2 input to the PLL. The standard reference clock is 100 MHz to the PLL, although an external reference may be used. The output of the PLL section of the AD9510 can therefore be programmed to many numbers in the range of 100 to 140 MHz, that may be subsequently divided in the PLL outputs. The dividers in the clock distribution section of the AD9510can be used to further divide the clock by 1 to 32, with the restriction only even numbers are used to make the clock a 50% duty cycle. A second divider device (an AD9510 with the PLL disabled) further divides the clock by 1 to 32.

The external clock and optional fixed oscillator are connected to the CLK1 input. The PLL must be programmed to use one of these two clock sources for the outputs.   The clock dividers on the outputs should be programmed to the same divisor to work with the standard logic.

The AD9510 is programmed during initialization of the card. All configuration registers are written, then an update command is sent to the PLL that makes the outputs update simultaneously. After an update, the clock is stable when the PLL status bit indicates a lock.

Timing Analysis

There are several timing parameters associated with the clock control circuitry that affect the measurement process. The following table summarizes two important effects.

Timing propagation delay through the logic for external clocks are shown for the maximum and typical timing. The external clocks go through one or two multiplexers, accounting for the differences in propagation delay to the various devices.

Jitter is summed as the root sum of squares for random jitter.

Clock Source	Clock Destination	Propagation Delay (ns)	Additive Jitter (ps RMS)
External clock or PXI_DSTARA	A/D and DAC conversion clocks	3.6 typical 5.0 maximum	0.07
100 MHz or PXIE_100M	PLL Reference clock	1.2 typical 1.5 maximum	0.05

Table 6. X3-Servo External Sample Clock Timing

Triggering

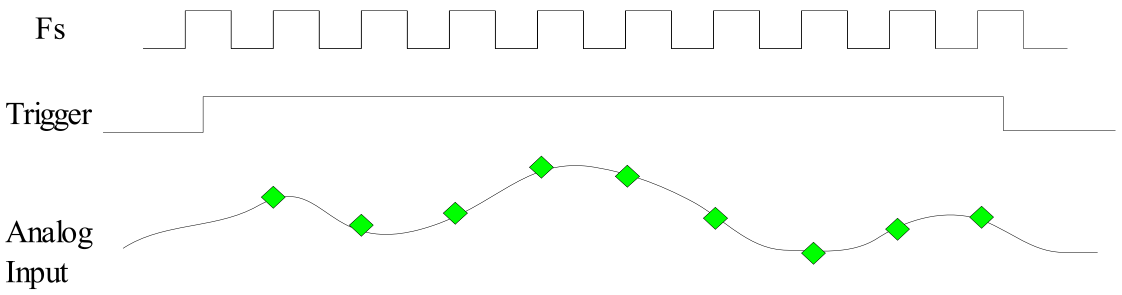
The X3-Servo has a triggering component in the FPGA that controls the data acquisition process. The sample clock specifies the instant in time when data is sampled, whereas triggering specifies when data is kept. This allows the application to collect data at the desired rate, and keep only the data that is required.

On the X3-Servo module, all A/D channels operate synchronously using the same clock and trigger. The trigger controls allows data to be acquired continuously, or during a specified time, as triggered by either a software or external trigger. Data can also be decimated to reduce data rates.

Trigger Mode	Data Collected/Played Back	Start Trigger	Stop Trigger
Continuous	All enabled channel pairs	Software or rising edge of external trigger	Software or falling edge of external trigger
Framed	N sample points for each of the enabled channel pairs	Software or rising edge of external trigger	Stops when N samples are collected back
Decimation	M points are discarded for every point kept. May be used with either trigger mode.	-	-

Table 7. Table 1: Trigger Modes

On the X3-Servo module, the sample rate is equal to the clock rate. The trigger component operates at the sample rate for its data collection process. The trigger is synchronized to the sample clock rate.



Samples are acquired for each sample period when trigger is true.

Figure 2. Sample Triggering

As shown in the diagram, A/D samples are captured when the sample period and the trigger are true on rising edges of the sample clock. The trigger is true in continuous mode after a rising edge on the trigger input, software or external, until a falling edge is found. The trigger is timed against the sample clock and may have a 0 to +1 A/D sample uncertainty for an asynchronous trigger input.

The trigger control on the X3-Servo module always ensures that a complete set of A/D samples for the time period are acquired no matter when the trigger is deasserted. This means that for an unsynchronized trigger input such as an external device, you will always get samples for all enabled channels no matter when trigger is enabled or disabled.

DAC updates are identical in functionality to the A/D sample rates, although a separate trigger is provided. A/D and DAC samples are always synchronous. DAC updates occur only when the DAC trigger is true on rising edges of the sample clock.

The Malibu software tools provide trigger source configuration and methods for software triggering, re-triggering in framed mode and trigger mode controls.

Trigger Source

A software trigger or external trigger can be used by the trigger controls. Software trigger can always be used, but external triggering must be selected. This prevents spurious triggers from noise on external inputs. The trigger source is level-sensitive for the continuous mode or edge-triggered for the framed mode triggering.

	External Trigger	JP1 Pin Number
A/D	TRIGGER0	34
DAC	TRIGGER1	68

Table 8. External Trigger Inputs

External triggers are LVTTL inputs and have the following electrical characteristics.

	Typical	Maximum
Logic High	> 1.4 V	3.6V** Up to 5.5V if a 100 ohm series resistor is used
Logic Low	< 0.7V	-0.3V
Input Impedance	>1M ohm	

Table 9. External Trigger Electrical Characteristics

Framed Trigger Mode

Framed trigger mode is useful for collecting data sets of a fixed size or playing a fixed number of samples each time the input trigger is fired. In framed mode, the trigger goes false once the programmed number of points N have been collected. Start triggers that occur during a frame trigger are ignored.

The maximum number of points per frame is 16,777,216 (2^24) points, while the minimum number of points is 2.

Data flow to the host is independent of the framed triggering mode. In most cases, packet sizes to the host are selected to be integer sub-multiples of the frame size to allow the entire data set to flow to the host. That way, the entire data frame can be moved immediately to the host without waiting for the next trigger frame. The only restriction is that packet sizes are limited to a minimum of 2 32-bit words, meaning that a packet must be at least 4 samples, the samples composed of one or more channels of data.

Decimation

The data may be decimated by a programmed ratio to reduce the data rate. This mode is usually used when the A/D rate is less than the DAC update rate. This allows the A/D to operate at sub-multiples to the DAC.

The decimation simply discards N points for every point kept – no averaging or filtering is used. When decimation is true, the number of points captured in the framed mode is the number of decimated points, in other words the discarded points do not count. Maximum decimation rate is 1/4095.

When decimation is used in the framed trigger mode, the number of points captured is after decimation. The frame count is always the actual number of points inserted into the FIFO.

FrameWork Logic Functionality

The FrameWork Logic implements a data flow for the X3-Servo that supports standard data acquisition and playback functionality. This data flow, when used with the supporting software, allows the X3-Servo to act as a data acquisition card with 2MB of data buffering and high speed data streaming to the host PCI Express. The example software for the X3-Servo demonstrates data flow control, logic loading and data logging.

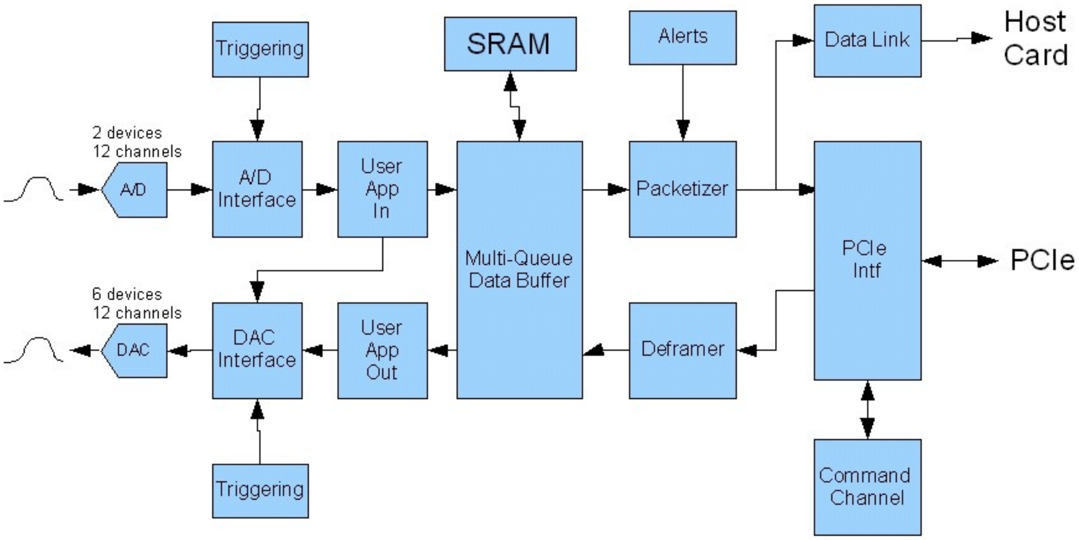


Figure 3. X3-Servo FrameWork Logic Data Flow

The data flow is driven by the data acquisition process . Data flows from the A/D devices into the A/D interface component in the FPGA as they are acquired. The data is then error corrected and the enabled channels are stored into the A/D data buffer when trigger is true, which is implemented a data queue in the SRAM. When data is available in the buffer, the packetizer pulls data from the queue, creates data packets of the programmed size and sends those to the PCIe interface logic. From here, the Velocia packet system controls the flow of data to the host. Data packets flow into host memory for consumption by the host program.

The DAC data flow is essentially the inverse of A/D flow: sample data flows from the PCI Express interface, into the DAC data buffer, and then into the DAC interface. In the DAC interface, the samples are modified to correct to analog gain and offset errors then converted to straight binary for the DAC device.

A special feedback mode allows A/D samples to flow back to the DAC channels as an example of servo feedback. The A/D samples flow through the U_APP_IN component so that servo controls can be implemented in that component. In this mode, the DAC channels are assumed to be 1:1 feedback of the A/D channels. The triggering and clock normally used for the A/D are used for the DAC outputs in the feedback mode. More advanced servo controls with multiple inputs and outputs can be built by modifying this structure in the FrameWork Logic.

The Board Basics and Host Communications chapters of this manual discuss the use of the packet data system used on the X3 module family. The X3-Servo module FrameWork Logic connects the data from A/D interface to the packet system by forming the 16-bit data into 32-bit words of consecutive enabled channels (channels 1|0, 3|2 etc). Status indicators for the A/Ds are integrated with the alert log to provide host notifications of important events for monitoring the data acquisition process, some of which are unique to the X3-Servo. DAC data is also stacked into 32-bit words by the host, then dissembled into channel data on the X3-Servo. The data is the stack of enabled channels so that 32-bit words are stacked from consecutively enabled channels channels 1|0, 3|2 etc).

The complete description of the FrameWork Logic is provided in the *FrameWork Logic User Guide* including the memory mapping, register definitions and functional behavior. This logic is about 20% of the available logic in the application FPGA (1.8M gate device). In many custom applications, unused logic functions can be deleted to free up gates for the new application.

Implementing Servo Controls

The X3-Servo can be used for servo control applications by embedding the control algorithms in the FPGA. The A/D devices, DACs, and digital IO are directly connected to the FPGA resulting in low latency and deterministic timing.

A typical servo control loop is shown in the following figure. The sensor inputs are digitized through the conditioning circuitry and A/D, then enter the FPGA. In the FPGA, the inputs are collected from the A/D devices, error corrected and are then ready for use. The U_APP_IN component is where the servo control algorithm is embedded. After the servo outputs are computed, they are written to the DAC and converted to analog outputs.

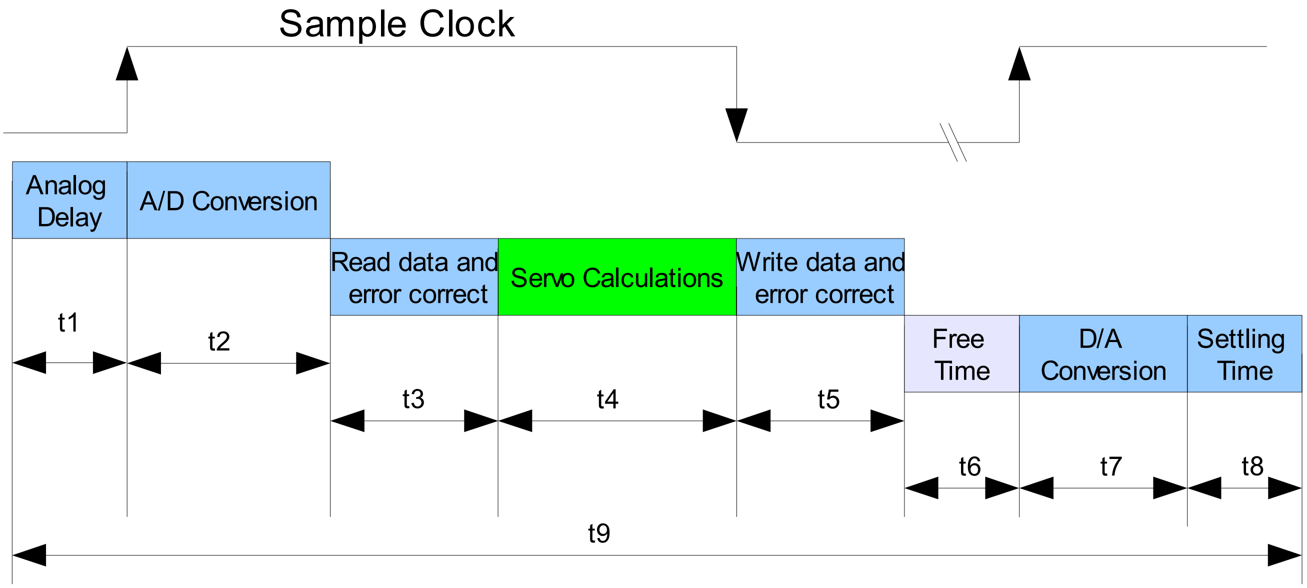


Figure 4. Servo Loop Timing for X3-Servo

Each step in the signal acquisition and conversion has a time delay that adds to the servo loop latency. The dominant time is the A/D conversion in most applications. The timings for the logic portions of the delay assume a 66.7 MHz system clock.

Parameter	Operation	Time (uS)	Comments
t_1	Analog delay	0.2	Analog input scaling and filtering. Timing is approximation for input changes 10% of full scale or less.
t_2	A/D Conversion	3.2	A/D conversion time from rising edge of the sample clock.
t_3	FPGA reads A/D data and performs error correction	1.4	Read A/D and error correction
t_4	Servo Calculations	?	Perform servo calculations. Algorithm dependent.
t_5	FPGA performs error correction and writes DAC data	0.7	Perform error correction and write DAC, process is initiated by falling edge of sample clock.
t_6	Free Time	?	Free time between when DAC data is written to when the DAC update occurs on sample clock rising edge.
t_7	D/A conversion	0.2	DAC conversion time
t_8	Setting Time	2.0	Analog output scaling and filtering
t_9	Total Servo Time	4.8 + t4 + t6 + 2.9	

Table 10. X3-Servo Timing for Servo Design

Total servo loop latency must also include the time required for servo loop timing. This can be accurately measured during simulation of the FPGA once the servo control algorithms have been added to the logic.

Power Controls and Thermal Design

The X3-Servo module has temperature monitoring and power controls to aid in system integration. Also, the module has been designed to include conduction cooling to improve heat dissipation from the module. These features can make the module more reliable in operation and also reduce power consumption.

System Thermal Design

The X3-Servo dissipates about 7W Watts typically for all analog channels running at full rate.

In an office or lab environment, the module can run without forced air cooling. Operating temperature is about 56C for a typical 22C office environment.

Conduction cooling or forced air cooling, or both, can be used to keep the module from exceeding its maximum operating temperature of 70C. If your operating environment exceeds 40C you should carefully consider how to cool the module in your application. If the module temperature exceeds 70 C as measured by the temperature sensor in the card, the module will disable the analog power supplies to reduce power consumption.

Conduction cooling is supported for the module and provides an effective method in many applications. A thermal plane in the card is attached to the center stripe on the card. The card can then be cooled by mounting the card on host card that supports conduction cooling. The conduction cooling method allows the module heat to be flowed out to the chassis. The thermal plane has NO electrical connection in the module and cannot be used as a ground.

Forced air cooling is also effective in cooling the module. An air flow of 5 CFM directly on the module is usually required above 40C to keep the module within its operating temperature range.

The front panel bracket is used for cooling and is attached to the thermal plane. The front panel is not electrically connected to the module ground plane- its is only connected to the thermal plane. When the module is operating, the front panel usually feels warm; this is normal.

Temperature Sensor and Over Temperature Protection

The temperature sensor is described in detail in the Board Basics chapter of this manual.   The temperature sensor is used to monitor the module temperature and protect it from overheating. Temperature readings from the module are provided for system monitoring and are also reported in each alert packet. During system development, it is a good idea to have a look at the temperature and verify that everything is OK inside the system during actual use.

When the module exceeds 85C, the analog power supplies shut down, reducing the power consumption to about 3W. The module can continue to communicate but no valid data will be collected. A temperature warning may be enabled via the Alert Log when the temperature is above 70C. If a warning occurs, it is best to do something either to reduce power consumption, such as tunning off the A/D channels, turning on a system fan or turning off other things in the system.

The application LED on the X3 module will flash when the module is too hot (>85C). The module must be completely powered down to restart once a failure occurs.

Reducing Power Consumption

The X3-Servo has power controls that allow the application software to power down unused channels and run in reduced power mode for the A/Ds. If you incorporate these into your application, you may be able to avoid problems later in hot installations.

Feature	Power Saved	Comments

A/D Nap	195 mW per device; 390mW total (min)	A/Ds enter NAP mode when the A/D run is false and consume 5 mW each
PLL power down	0.3W	PLL off – must use external clock
Application FPGA not configured	1.5W	Must reload the FPGA to resume operation.
33 MHz system clock	0.5	33 MHz FPGA system clock. Data rate to host is limited to <100 MB/s typically.

Table 11. Reduced Power Options

The 33 MHz system clock feature requires that the card reconfigured by installing a 0 ohm jumper for R228. This jumper is located near the PCIe interface device (XIO2000A) and is on the back of the card. The factory can pre-configure this if you decide to use this option in production. As shipped, the system clock is 66 MHz because this allows the system logic to support custom logic developers more easily. Tests have shown that this reduces operating temperature by 4 C for room temperature testing with no forced air. Total data rate from the module must be limited to 50MB/s when a 33 MHz clock is used.

Alert Log

Overview

X3 modules have an Alert Log that can be used to monitor the data acquisition process and other significant events. Using alerts, the application can create a time history of the data acquisition process that shows when important events occurred and mark the data stream to correlate system events to the data.. This provides a precision timed log of all of the important events that occurred during the acquisition and playback for interpretation and correlation to other system-level events. Alerts for critical system events such as triggering, data overruns, analog overranges, and thermal warnings provide the host system with information to manage the module.

The Alert Log creates an alert packet whenever an enabled alert is active. The packet includes information on the alert, when it occurred in system time, and other status information. The system time is kept in the logic using a 32-bit counter running at the sample clock rate. Each alert packet is transmitted in the packet stream to the host , marked with a Peripheral Device Number corresponding to the Alert Log.

The Alter Log allows X3 modules to provide the host system with time-critical information about the data acquisition to allow better system performance. System events, such as over-ranges, can be acted on in real-time to improve the data acquisition quality. Monitoring functions can be created in custom logic that triggers only when the digitized data shows that something interesting happened. Alerts make this type of application easier for the host to implement since they don't require host activity until the event occurs.

Types of Alerts

Alerts can be broadly categorized into system, IO and software alerts.

System alerts include monitoring functions such as temperature, time stamp rollover and PLL lost. These alerts just help keep the system working properly. The temperature warning should be used increase temperature monitor and to prepare to shut down if necessary because thermal overload may be coming. Better to shut down than crash in most cases. The temperature failure alert tells the system that the module actually shut itself down. This usually requires that the module be restarted when conditions permit.

The data acquisition alerts, including over ranges, overflows and triggering, tell the system that important events occurred in the data acquisition process. Overflow is particularly bad – data was lost and the system should try to alleviate the system by unclogging the data pipe, or just start over. If you get an overrange alert, then the data may just be bad for a while but acquisition can continue. Modules with programmable input ranges can use this to trigger software range changes.

Software alerts are used to tag the data. Any message can be made into an alert packet so that the data stream logged includes system information that is time-correlated to the data.

Table 12. Alert Types

Alert	Purpose
Timestamp rollover	The 32-bit timestamp counter rolled over. This can be used to extend the timestamp counter in software.
Software Alert	The host software can create alerts to tag the data stream.
Over Temperature Alarm/ Sensor Failure	The module temperature exceeded 85C.
Temperature Warning	The module temperature exceeded 70C.
PLL Lost	The sample clock PLL lost lock. The PLL must be reconfigured.
ADC Queue Overflow	The ADC data queue overflowed indicating the the host did not consume the data quickly enough.
ADC Trigger	The ADC trigger went active.
ADC Overrange	An ADC channel was overranged.
DAC Trigger	The DAC trigger went active.
DAC Queue Underflow	The DAC data queue underflowed indicating the the host did provide data when required by the DAC

Alert Packet Format

Alert data packets have a fixed format in the system The Peripheral Device Number (PDN) is programmable in the software and is included in the packet header, thus identifying the alert data packets in the data stream. The packet shows the timestamp in system time, what alerts were signaled and a status word for each alert.

Dword #	Description
0	Header 1: PDN & Total #, N, of Dwords in packet (e.g. Headers + data payload)
1	Header 2: 0x00000000
2	Alerts Signaled
3	Timestamp
4	0
5	Software Word

6	temp_sensor_error & temp_error & "00" & X"000" & temp_data;
7	temp_warning & "000" & X"000" & temp_data;
10..8	0
12	X"1303000" & "000" & mq_overflow(0);
15..13	0
16	X"13030001"
17	0
35..13	Unused

Table 13. Alert Packet Format

Since alert packets contain status words such as temperature for each packet, a software alert can essentially be used to read temperature of the module and so that it can be recorded.

Software Support

Applications have different needs for alert processing. Aside from the bulk movement of data, most applications require some means of handling special conditions such as post-processing upon receipt of a stop trigger or closing a driver when an acquisition is completed.

When the alert system is enabled, the module logic continuously monitors the status of the peripheral (usually analog) hardware present on the baseboard and generates an alert whenever an alert condition is detected. It's also possible for application software to generate custom alert messages to tag the data stream with system information.

The Malibu software provides support for alert configuration and alert packet processing. See the software manual for usage.

Tagging the Data Stream

The Alert Log can be used to tag the data stream with system information by using software alerts. This helps to provide system-level correlation of events by creating alert packets in the data stream created by the host software. Alert packets are then created by the X3 module and are in the stream of data packets from the module. For example it is often interesting when something happens to the unit under test, such as a change in engine speed or completion of test stimulus.

Using the X3-Servo

Where to start?

The best place to start with the X3-Servo module is to install the module and use the SNAP example to acquire some data. This program lets you log data from the module and use all the features like triggering, clocks, alerts and calibration ROM. You can use this program to acquire some data and log it to disk. This should let you verify that the module can acquire the data you want and give you a quick start on deciding what sample rates to use, how to trigger the data acquisition best for your application, and just get familiar with using the module.

The program also shows how to use BinView, a data analysis and viewing program by Innovative, that will let you see what you acquired in detail. Both time domain and frequency domain data can be viewed and analyzed. Data can also be exported to programs like Excel and MATLAB for further analysis.

Before you begin to write software, taking a look at SNAP will allow you see everything working. You can then look at the code for SNAP and modify it for your application or grab code from it that is useful.

A similar program for DAC outputs is provided call WAVE. WAVE allows you to generate various waveforms on the host and play them out through the DAC channels. DAC features such update clock controls and channel enables are shown. WAVE allows you to become acquainted with the features and provides an example to the programmer for using the DACs.

Getting Good Analog Performance

The X3-Servo has analog dynamic range exceeding 90 dB. To take advantage of this, it is important to do the following:

- Use differential input signals to eliminate system noise. Single-ended signals give typically 10 to 20 dB worse results because of noise pickup.
- Band limit input signals. Even though the A/D has filtering and rejects most out-of-band noise, it is a good idea to filter the incoming signal just to get rid of as much noise as possible.
- Scale your input signals to utilize the full range of the input and outputs. Make the signal as big as possible so that the noise is a not as much a factor. Custom ranges can be ordered if necessary.
- Use a high quality shielded cable. The MDR68 cable was selected because it has a foil shield and delivers near-coax performance.
- Twist DAC outputs with the return current wire as a pair. Use the GND on the adjacent pin for each DAC output.
- Reference input signals to the module ground. Be sure not to introduce ground loops.

If you decide to test the X3-Servo to verify its performance, be aware that most signal sources are not good enough without additional filtering and careful use. Most single-ended lab instruments are limited by their distortion to about 90 dB. Post-filter is necessary to clean them up if you want to test the X3-Servo.

Application Logic

The application logic ***must*** be loaded after every system boot-up or reset. There is no on-card storage for the logic image. The logic can be loaded using the LogicLoad software applet or is loaded as part of the application itself, such as SNAP. If you write your own application, you will need to either use LogicLoad or incorporate a logic loader in the application. The code in SNAP is a good example of how to do this. Logic loading takes about 2-3 seconds using the PCI interface.

Calibration

Every A/D and DAC sample is error corrected on the X3-Servo module in real-time by the application FPGA. This error correction is done as the samples flow through the FPGA and is done digitally. This results in improved performance and reliability for the module because the error correction does not change over time or temperature.

The basic error terms for offset and scale factor are corrected by the logic. This is a first order error correction where

$$y = mx + b$$

wherein x = the input sample, m = gain correction and b = offset correction. The resultant samples are the error corrected output samples. Trim range is about 1.5 for gain and 10% for offset.

Production Calibration

Each X3-Servo is calibrated as part of the production tests performed. The calibration results are provided on the production test report with each module. The results of the calibration are stored in the on-board EEPROM memory. These calibration values are used by the logic to correct the analog errors and are loaded into the A/D and DAC components as part of the initialization by the software.

The calibration technique used during factory test determines the A/D errors by first measuring the output with ground connected, then a known voltage. A value close to full scale such as 9.8V and -9.8V are recommended. The measurements are the average of 64K samples at each test voltage. From these three points across the input range, the gain and offset errors are calculated.

DACs outputs are calibrated using a precision voltmeter. Outputs of 0V, 9.5V and -9.5V are commanded on the module and these points are used to calculate the gain and offset errors. The voltmeter provides a high precision measurement that is the average over a 1 second period, effectively rejecting the noise for this measurement.

All test voltages are measured as part of the procedure with NIST traceable equipment. Production calibration is performed at room temperature (~22C) with the module operating temperature at about 50C. A minimum warm-up period of one minute is used for the testing.

Under normal circumstances, calibration is accurate for one year. For recalibration, the module can be sent to Innovative or recalibrated using a similar test procedure.

Updating the Calibration Coefficients

A software applet for writing the calibration coefficients to the EEPROM is provided (EEPROM.exe). New coefficients are simply typed into the offset and gain field for each channel.

Calibration coefficients for gain should not be greater than 1.1 and offset < 0x8000 . If the calculated coefficients are larger than this, they are either wrong or the channel is damaged.

Performance Data

Power Consumption

The X3-Servo requires the following power for typical operation with when using the FrameWork Logic. This typical number assumes a 67 MHz system clock rate and all analog channels active for the application logic.

Table 14. X3-Servo Power Consumption

Voltage	Maximum Allowed Current (A)	Condition	Typical Current Required (A)	Typical Power (W)	Derived from	Supplies these Devices
3.3V	5A (recommended)	Before application logic is loaded	0.95	3.2	Direct connect to the PCIe host	All devices; on-card power supplies use 3.3V as source
3.3V	5A (recommended)	After application logic is loaded	1.62	5.4	Direct connect to the PCIe host	All devices; on-card power supplies use 3.3V as source
3.3V	5A (recommended)	Running all A/D channels at full rate (250 ksps)	3.6	11.9	Direct connect to the PCIe host	All devices; on-card power supplies use 3.3V as source
12V	-		0	0	Not required	-
Total Power		Typical full speed operation		**11.9**		

Surge currents occur initially at power-on and after application logic initialization. The power-on surge current lasts for about 10 ms @ 5A on the 3.3V supply. This surge is due primarily to charging the on-card capacitors and the startup current of the FPGAs. After initial power-up, the logic configuration will also result in a step change to the current consumption because the logic will begin to operate. In our testing and measurements, this has not been a surge current as much as a just a step change in the power consumption.

Power consumption varies and is primarily as a function of the logic design. Logic designs with high utilization and fast clock rates require higher power. Since calculating power consumption in the logic requires many details to be considered, Xilinx tools such as XPower are used to get the best estimates.

It is important that any custom logic design have a substantial safety margin for the power consumption. Allowance for decreased power supply efficiency due to heating can account for 10% derating. Also, dynamic loads should be considered so that peak power is adequate. In many cases a factor of two for derating is recommended.

Environmental

Table 15. X3-Servo Environmental Limits

Condition	Limits
Operating Temperature	0 to 55 C ambient (70C as measured by the on-card temp sensor)
Humidity	5 to 95 %, non condensing
Storage Temperature	-30 to 85 C
Forced Air Cooling	Forced air cooling required with a minimum of 5 CFM for 27C ambient.
Vibration, operating	ETS 300 019- 1.3 [R3], class 3.3
Vibration, storage	ETS 300 019- 1.1 [R1], class 1.2
Vibration, transportation	ETS 300 019- 1.2 [R2], class 2.3 except for free-fall: class 2.2

Analog Input

A summary of the analog performance follows for the X3-Servo module.

All tests performed at room temperature, with no forced air cooling unless noted. Test environment was PCIe adapter card in PC running testbed software using FrameWork Logic.

Table 16. X3-Servo Analog Input Performance Summary

Parameter	Measured	Units	Test Conditions
Bandwidth	-1.0	dB	0 to 200 kHz
	320	kHz	-3dB, Analog Gain = 1
Input Range	20	Vp-p differential	Standard on X3-Servo, calibration results may limit input range to 97% of full scale nominal.
Offset	3	mV	Factory calibration, average of 64K samples
Gain	0.05	%	Factory calibration, average of 64K samples
Ground Noise	1578	uVp-p	Input Grounded, sample rate = 250 ksps, 64k samples
Ground Noise	<-100	dB	Input Grounded, sample rate = 250 ksps, 64K sample FFT, non-averaged

Parameter	Measured	Units	Test Conditions
Crosstalk	<-100	dB	100 kHz, 2Vp-p input, cable included, all channels, at noise floor
Common Mode Rejection	>100	dB	1.01k Hz, 5Vp-p differential
Intermodulation Distortion	-101.2	dB	9 kHz and 11 kHz sine, 5Vp-p each, differential input

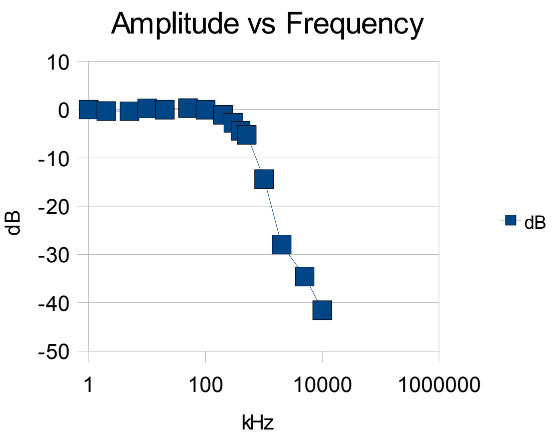


Figure 5. Analog Input Bandwidth 0 to 10 MHz (sample rate = 250 ksps, Vin= 5Vp-p)

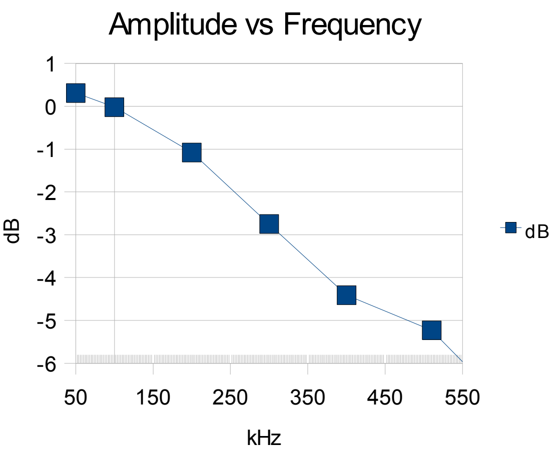
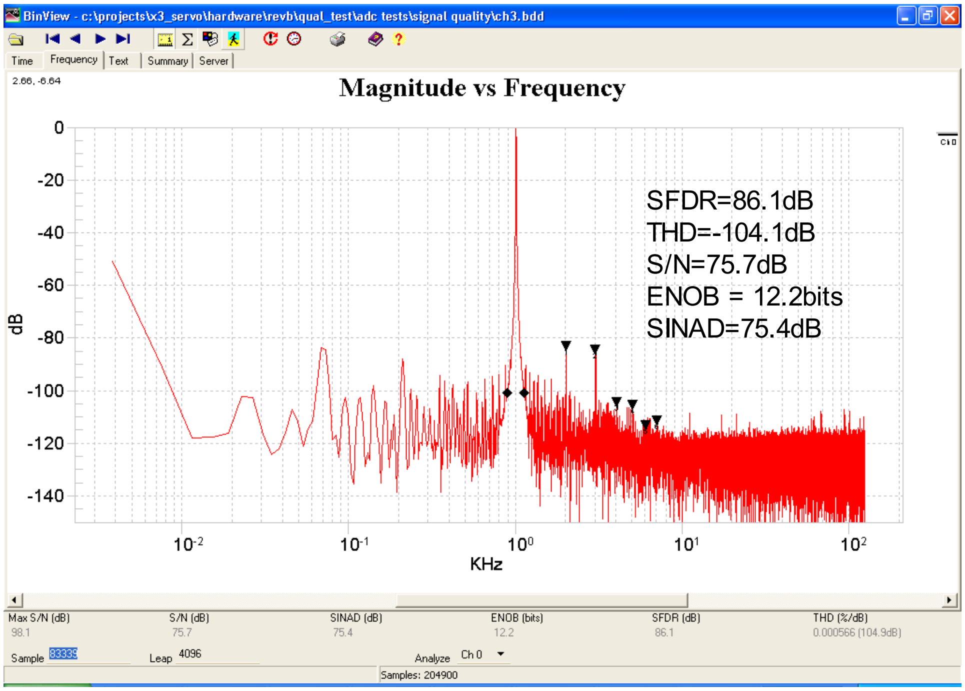


Figure 6. Analog Input Bandwidth 50 to 550 kHz (sample rate = 250 ksps, Vin= 5Vp-p)



Max S/N (dB) 98.1

S/N (dB) 75.7

SINAD (dB) 75.4

ENOB (bits) 12.2

SFDR (dB) 86.1

THD (%/dB) 0.000566 (104.9dB)

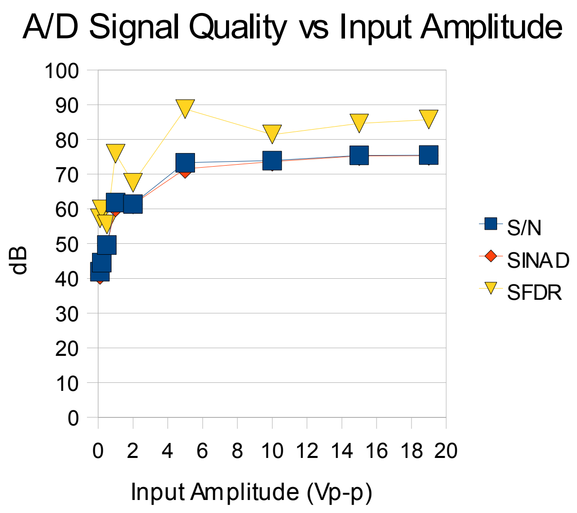
Sample 83339

Leap 4096

Analyze Ch 0

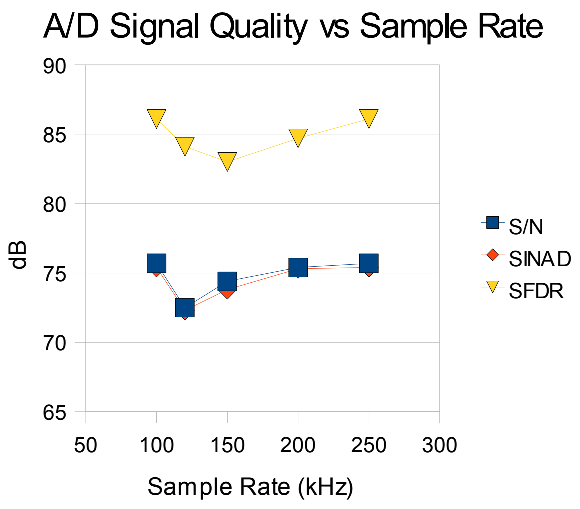
Samples: 204900

Figure 7. Signal quality measurement (1.01 kHz input, 5Vp-p, sample rate = 250 ksps)



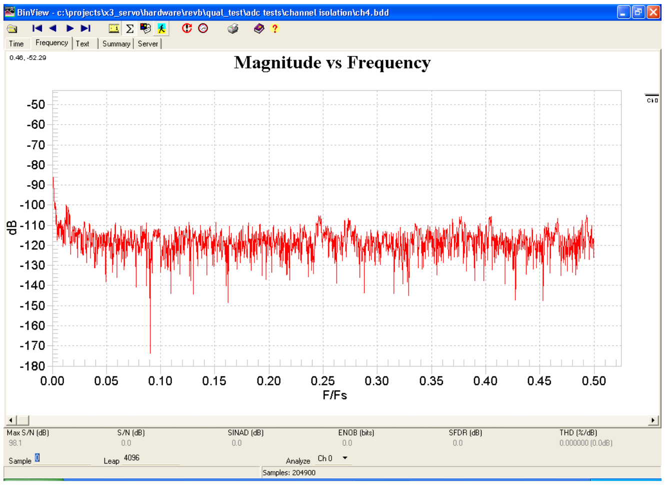
Input amplitude	S/N	SINAD	SFDR	ENOB	THD
Vp-p	dB	dB	dB	bits	dB
0.1	41.9	41	57.3	6.5	-60.7
0.2	44.5	43.3	59.8	6.9	-61
0.5	49.6	49.4	55.5	7.9	-80.9
1	61.8	60.4	75.9	9.7	-76.5
2	61.4	61.3	67.5	9.9	-95.1
5	73.3	71.5	88.7	11.6	-86.3
10	73.9	73.6	81.4	11.9	-104.2
15	75.4	75.2	84.6	12.2	-107.1
19	75.5	75.3	85.7	12.2	-106

Figure 8. Signal Quality vs Input Amplitude (sample rate = 250 ksps, 1.01 kHz sine)



Sample Rate	S/N	SINAD	SFDR	ENOB	THD
kHz	dB	dB	dB	bits	dB
100	75.7	75.4	86.1	12.2	-104.9
120	72.5	72.3	84.1	11.7	-105.8
150	74.4	73.8	83	12	-97
200	75.4	75.3	84.7	12.2	-109.5
250	75.7	75.4	86.1	12.2	-104.9
average	74.2	73.83	84.4	11.97	-102.57

Figure 9. Signal Quality vs Sample Rate (Vin = 5Vp-p, 1.01 kHz sine)



BinView - c:\projects\x3_servo\hardware\revb\qual_test\adc tests\channel isolation\ch4.bdd

Max S/N (dB)	S/N (dB)	SINAD (dB)	ENOB (bits)	SFDR (dB)	THD (%/dB)
98.1	0.0	0.0	0.0	0.0	0.000000 (0.0dB)

Sample 0 Leap 4096 Analyze Ch 0

Samples: 204900

Figure 10. Noise floor (grounded input, Fs= 250 ksps)

Analog Output

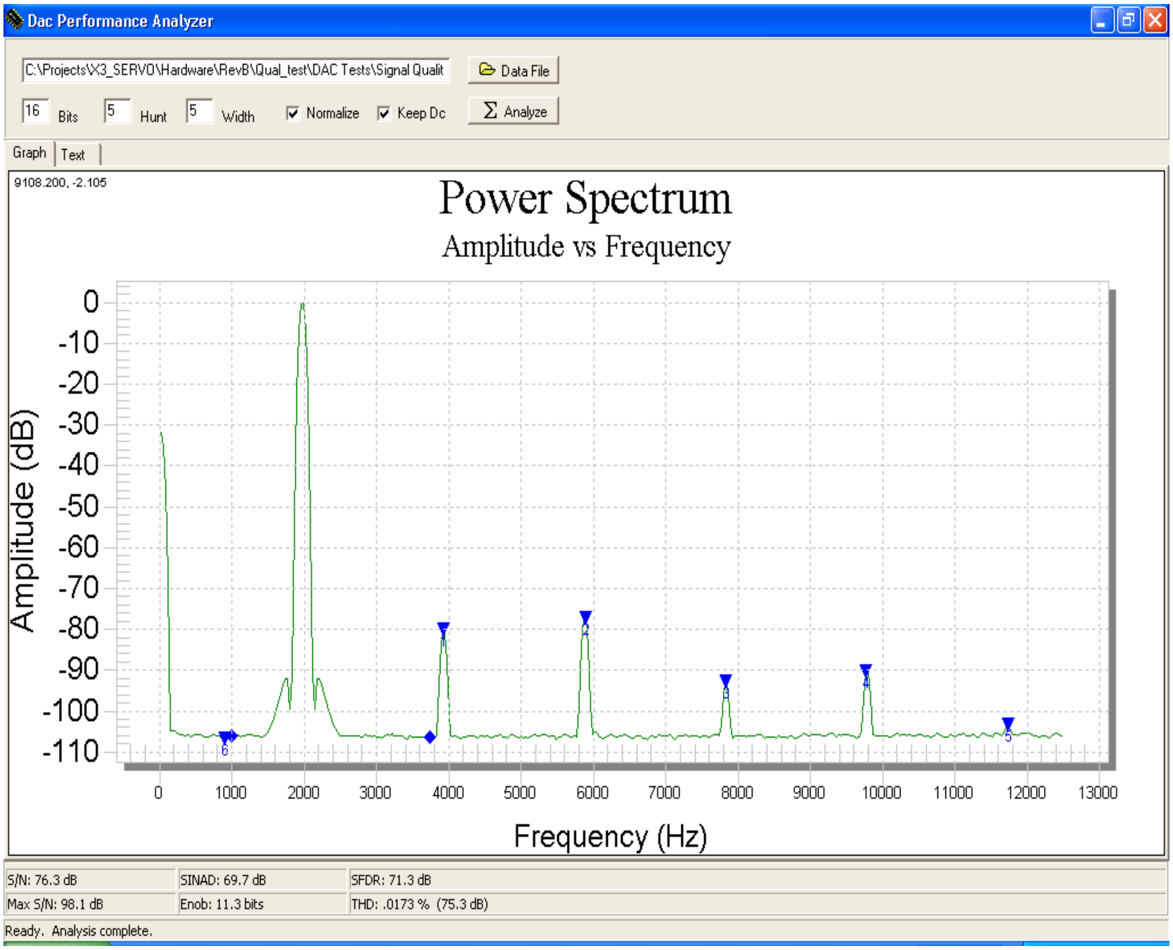
A summary of the analog output performance follows for the X3-Servo module.

All tests performed at room temperature, with no forced air cooling unless noted. Test environment was PCIe adapter card in PC running testbed software using FrameWork Logic.

Table 17. X3-Servo Analog Output Performance Summary

Parameter	Measured	Units	Test Conditions
Bandwidth	0.6	dB	0 to 200 kHz
	500	kHz	-2.5dB
Output Range	20 +0/-4%	Vp-p differential	Standard on X3-Servo, calibration results may limit input range to 97% of full scale nominal.
Offset	3	mV	Factory calibration, average of 64K samples
Gain	0.05	%	Factory calibration, average of 64K samples
Ground Noise	1578	uVp-p	Input Grounded, sample rate = 250 ksps, 64k samples
Ground Noise	<-100	dB	Input Grounded, sample rate = 250 ksps, 64K sample FFT, non-averaged

Parameter	Measured	Units	Test Conditions
Crosstalk	<-90	dB	1 kHz, 19Vp-p sine on active channel input, cable included, all channels, at noise floor
Settling Time	2.85	µS	4V step input.



Dac Performance Analyzer

C:\Projects\X3_SERVO\Hardware\RevB\Qual_test\DAC Tests\Signal Qualit

16 Bits 5 Hunt 5 Width ☑ Normalize ☑ Keep Dc

9108.200, -2.105

S/N: 76.3 dB | SINAD: 69.7 dB | SFDR: 71.3 dB

Max S/N: 98.1 dB | Enob: 11.3 bits | THD: .0173 % (75.3 dB)

Ready. Analysis complete.

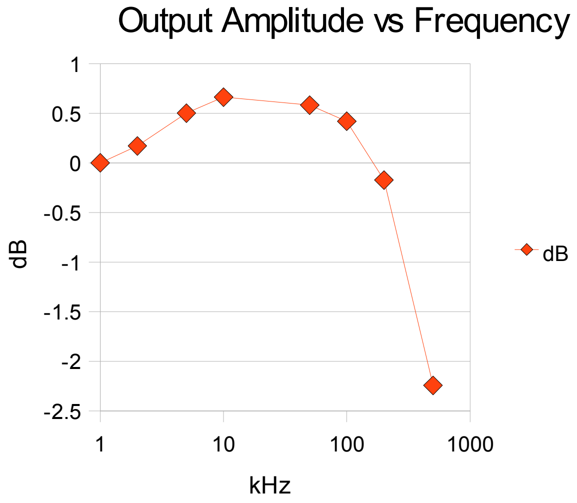


Figure 11. Output Amplitude vs Frequency

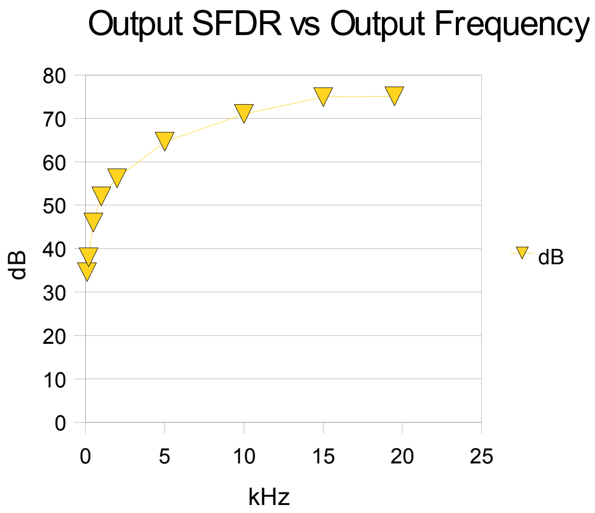


Figure 12. Output Spurious Free Dynamic Range (SFDR) vs Frequency

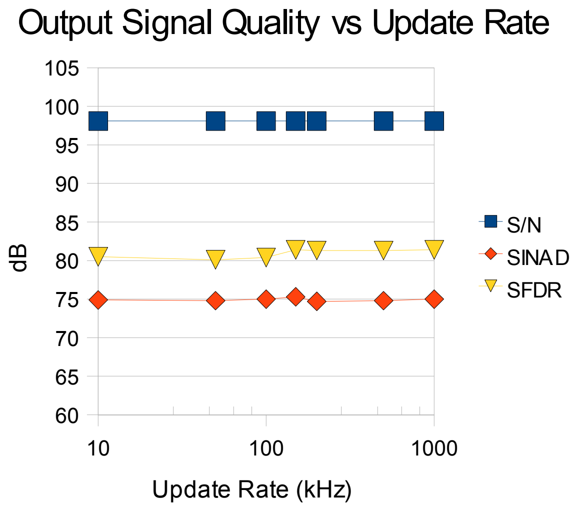


Figure 13. Output Signal Quality vs Update Rate

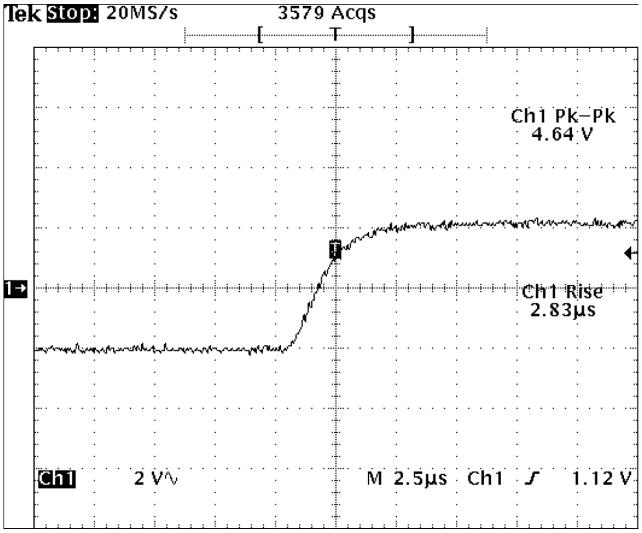


Figure 14. Output Settling Time for 4V Step

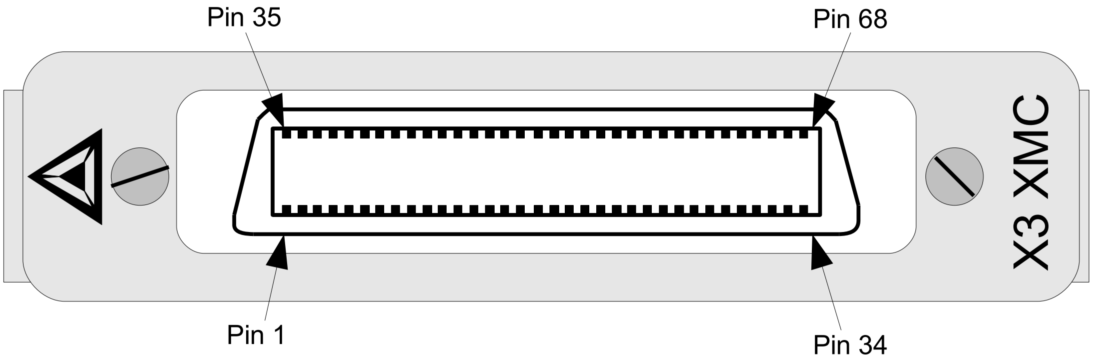
Connectors

Input Connector JP1

JP1connector is the front panel connector for the analog inputs, external clock and external trigger inputs.

Connector Type:	MDR
Number of Connections:	68
Connector Part Number	3M part number 10268-55H3VC
Mating Connector:	3M part number 10168-6000EC (IDC) Digikey (www.digikey.com) P/N MPB68A-ND
Cable	Innovative part number 65057 MDR68 male to-male, 36 inches (0.91meters)

This is the MDR68 as viewed from the front panel.



X3 XMC Front Panel View

X3-Servo JP1 Front Panel Connector Pin Assignments

DAC 0	1	O	O	35	DAC 1
AGND	2	P	P	36	AGND
DAC 2	3	O	O	37	DAC 3
AGND	4	P	P	38	AGND
DAC 4	5	O	O	39	DAC 5
AGND	6	P	P	40	AGND
DAC 6	7	O	O	41	DAC 7
AGND	8	P	P	42	AGND
DAC 8	9	O	O	43	DAC 9
AGND	10	P	P	44	AGND
DAC 10	11	O	O	45	DAC 11
AGND	12	P	P	46	AGND
A/D 11 IN-	13	I	I	47	A/D 11 IN+
A/D 10 IN-	14	I	I	48	A/D 10 IN+
A/D 9 IN-	15	I	I	49	A/D 9 IN+
A/D 8 IN-	16	I	I	50	A/D 8 IN+
A/D 7 IN-	17	I	I	51	A/D 7 IN+
A/D 6 IN-	18	I	I	52	A/D 6 IN+
A/D 5 IN-	19	I	I	53	A/D 5 IN+
A/D 4 IN-	20	I	I	54	A/D 4 IN+
A/D 3 IN-	21	I	I	55	A/D 3 IN+
A/D 2 IN-	22	I	I	56	A/D 2 IN+
A/D 1 IN-	23	I	I	57	A/D 1 IN+
A/D 0 IN-	24	I	I	58	A/D 0 IN+
AGND	25	P	P	59	AGND
FP DIO 0	26	I/O	I/O	60	FP DIO 1
FP DIO 2	27	I/O	I/O	61	FP DIO 3
FP DIO 4	28	I/O	I/O	62	FP DIO 5
FP DIO 6	29	I/O	I/O	63	FP DIO 7
FP DIO 8	30	I/O	I/O	64	FP DIO 9
FP DIO 10	31	I/O	I/O	65	FP DIO 11
AGND	32	P	P	66	AGND
EXT CLK +	33	I	I	67	EXT CLK -
TRIGGER1	34	I	I	68	TRIGGER0

Note : - = No Connect, P = Power, I= Input, O = Output, I/O = Bidirectional. All are relative to X3 module.

XMC P15 Connector

P15 is the XMC PCI Express connector to the host.

Connector Types:	XMC pin header, 0.05 in pin spacing, vertical mount
Number of Connections:	114, arranged as 6 rows of 19 pins each
Connector Part Number	Samtec ASP-105885-01
Mating Connector:	Samtec ASP-105884-01

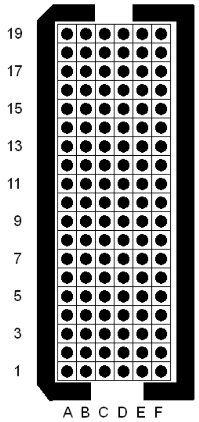


Figure 15. P15 XMC Connector Orientation

	Column					
Row	A	B	C	D	E	F
1	PET0p0	PET0n0	3.3V			VPWR
2	GND	GND		GND	GND	MRSTI#
3			3.3V			VPWR
4	GND	GND		GND	GND	MRSTO#
5			3.3V			VPWR
6	GND	GND		GND	GND	+12V
7			3.3V			VPWR
8	GND	GND		GND	GND	-12V
9						GA0
10	GND	GND		GND	GND	VPWR
11	PER0p0	PER0n0	MBIST#			MPRESENT#
12	GND	GND	GA1	GND	GND	VPWR
13			3.3VAUX			MSDA
14	GND	GND	GA2	GND	GND	VPWR
15						MSCL
16	GND	GND	MVMRO	GND	GND	
17						
18	GND	GND		GND	GND	
19	PEX REFCLK+	PEX REFCLK-		WAKE#	ROOT#	

Table 18. X3 XMC Connector P15 Pinout

Note: All unlabeled pins are not used by X3 modules but may defined in VITA42 and VITA42.3 specifications.

Table 19. P15 Signal Descriptions

Signal	Description	P15 Pin
PET0p0/PET0n0	PCI Express Tx +/-	A1/B1
PER0p0/PER0n0	PCI Express Rx +/-	A11/B11
PEX REFCLK+/-	PCI Express reference clock, 100 MHz +/-	A19/B19
MRSTI#	Master Reset Input, active low	F2
MRSTO#	Master Reset Output, active low	F4
GA0	Geographic Address 0	F9
GA1	Geographic Address 1	C12
GA2	Geographic Address 2	C14
MBIST#	Built-in Self Test, active low	C11
MPRESENT#	Present, active low	F11
MSDA	PCI Express Serial ROM data	F13
MSCL	PCI Express Serial ROM clock	F15
MVMRO	PCI Express Serial ROM write enable	C16
WAKE#	Wake indicator to upstream device, active low	D19
ROOT#	Root device, active low	E19

XMC P16 Connector

P16 is the XMC secondary connector to the host and is used for digital IO, data link and triggering functions.

Connector Types:	XMC pin header, 0.05 in pin spacing, vertical mount
Number of Connections:	114, arranged as 6 rows of 19 pins each
Connector Part Number	Samtec ASP-105885-01
Mating Connector:	Samtec ASP-105884-01

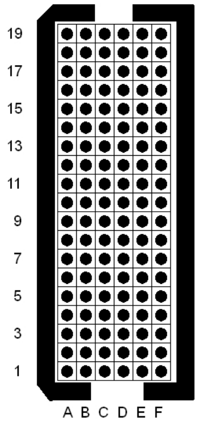


Figure 16. P16 XMC Connector Orientation

Table 20. X3 XMC Secondary Connector P16 Pinout

	Column					
Row	A	B	C	D	E	F
1	-	-	DIO0/PXI_TRIG0	-	-	DIO19
2	DGND	DGND	DIO1/PXI_TRIG1	DGND	DGND	DIO20
3	-	-	DIO2/PXI_TRIG2	-	-	DIO21
4	DGND	DGND	DIO3/PXI_TRIG3	DGND	DGND	DIO22
5	-	-	DIO4/PXI_TRIG4	-	-	DIO23
6	DGND	DGND	DIO5/PXI_TRIG5	DGND	DGND	DIO24
7	-	-	DIO6/PXI_TRIG6	-	-	DIO25
8	DGND	DGND	DIO7/PXI_TRIG7	DGND	DGND	DIO26
9	DIO38 /PXI_DSTARA+	DIO39 /PXI_DSTARA-	DIO8/PXI_STAR	DIO40 /PXIE_100M+	DIO41 /PXIE_100M-	DIO27
10	DGND	DGND	DIO9/ PXIE_SYNC100+	DGND	DGND	DIO28
11	-	-	DIO10 /PXIE_SYNC100-	-	-	DIO29
12	DGND	DGND	DIO11	DGND	DGND	DIO30
13	-	-	DIO12	-	-	DIO31
14	DGND	DGND	DIO13	DGND	DGND	DIO32
15	-	-	DIO14	-	-	DIO33
16	DGND	DGND	DIO15	DGND	DGND	DIO34
17	-	-	DIO16	-	-	DIO35 /PXI_10M
18	DGND	DGND	DIO17	DGND	DGND	DIO36 /PXI_LBL6
19	DIO42/ PXIE_DSTARB+	DIO43/ PXIE_DSTARB-	DIO18	DIO_CLK+ /PXI_DSTARC+	DIO_CLK-/PXI_DSTARC-	DIO37 /PXI+LBR_6

Note: all unused pins are not labeled.

Table 21. P16 Signal Descriptions

Signal	Description	P16 Pin
DIO0/PXI_TRIG0	Digital IO 0/ PXIE trigger 0	C1
DIO/PXI_TRIG1	Digital IO 1/ PXIE trigger 1	C2
DIO2/PXI_TRIG2	Digital IO 2/ PXIE trigger 2	C3
DIO3/PXI_TRIG3	Digital IO 3/ PXIE trigger 3	C4
DIO4/PXI_TRIG4	Digital IO 4/ PXIE trigger 4	C5
DIO5/PXI_TRIG5	Digital IO 5/ PXIE trigger 5	C6
DIO6/PXI_TRIG6	Digital IO 6/ PXIE trigger 6	C7
DIO7/PXI_TRIG7	Digital IO 7/ PXIE trigger 7	C8
DIO8/PXI_STAR	Digital IO 8/ PXIE star trigger	C9
DIO9/PXIE_SYNC100+	Digital IO 9/ PXIE sync 100+	C10
DIO10/PXIE_SYNC100-	Digital IO 10/ PXIE sync 100-	C11
DIO11	Digital IO 11	C2
DIO12	Digital IO 12	C13
DIO13	Digital IO 13	C14
DIO14	Digital IO 14	C15
DIO15	Digital IO 15	C16
DIO16	Digital IO 16	C17
DIO17	Digital IO 17	C18
DIO18	Digital IO 18	C19
DIO19	Digital IO 19	F1
DIO20	Digital IO 20	F2
DIO21	Digital IO 21	F3
DIO22	Digital IO 22	F4
DIO23	Digital IO 23	F5
DIO24	Digital IO 24	F6
DIO25	Digital IO 25	F7

Signal	Description	P16 Pin
DIO26	Digital IO 26	F8
DIO27	Digital IO 27	F9
DIO28	Digital IO 28	F10
DIO29	Digital IO 29	F11
DIO30	Digital IO 30	F12
DIO31	Digital IO 31	F13
DIO32	Digital IO 32	F14
DIO33	Digital IO 33	F15
DIO34	Digital IO 34	F16
DIO35/PXI_10M	Digital IO 35/ PXI 10M Ref Clk	F17
DIO36/PXI_LBL6	Digital IO 36/ PXI local bus left 6	F18
DIO37/PXI+LBR_6	Digital IO 37/ PXI local bus right 6	F19
DIO38/PXI_DSTARA+	Digital IO 38/ PXIE Differential STAR A+	A9
DIO39/PXI_DSTARA-	Digital IO 39/ PXIE Differential STAR A-	B9
DIO40/PXIE_100M+	Digital IO 40/ PXIE 100M ref clk-	D9
DIO4/PXIE_100M-	Digital IO 41/ PXIE 100M ref clk-	E9
DIO42/PXIE_DSTARB+	Digital IO 42/ PXIE Differential STAR B+	A19
DIO43/PXIE_DSTARB-	Digital IO 43/ PXIE Differential STAR B-	B19
DIO_CLK+/PXI_DSTARC+	Digital IO Clk+/ PXIE Differential STAR C+	D19
DIO_CLK-/PXI_DSTARC-	Digital IO Clk-/ PXIE Differential STAR C-	E19

Note: PXI Express signals are only available when PXIE adapter card is used.

Xilinx JTAG Connector

JP3 is used for the Xilinx JTAG chain. It connects directly with Xilinx JTAG cables such as Parallel Cable IV or Platform USB.

Connector Types:	14-pin dual row male header, 2mm pin spacing, right angle
Number of Connections:	14, arranged as 2 rows of 7 pins each
Connector Part Number	Samtec TMM-107-01-L-D-RA or equivalent
Mating Connector:	AMP 111623-3 or equivalent

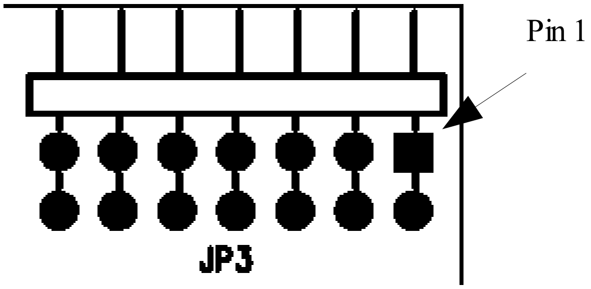


Figure 17. X3-Servo J3 Orientation

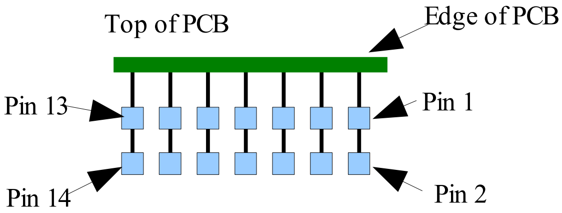


Figure 18. X3-Servo J3 Side View

Table 22. X3 JP3 Xilinx JTAG Connector Pinout

Pin	Signal	Direction
1,3,5,7,9,11,13	Digital Ground	Power
2	3.3V	Power
4	TMS	I
6	TCK	I
8	TDO	O
10	TDI	I
12,14	No Connect	-

Mechanicals

The following diagram shows the X3-Servo connectors and physical locations. The bottom view of the XMC is shown which is the side against the host card when mounted. The XMC conforms to IEEE 1386 form factor, 75mm x 150mm. The spacing to the host card is 10 mm and consumes a single slot in desktop and Compact PCI/PXI chassis.

The following views of the X3-Servo show the connector placements. The bottom view of the board is faces the carrier card when installed. An EMI shield over the analog section is normally installed.

Detailed drawings for mechanical design work are available through technical support.

Note that the “bottom ” of the card is the side with the XMC and front panel connectors.

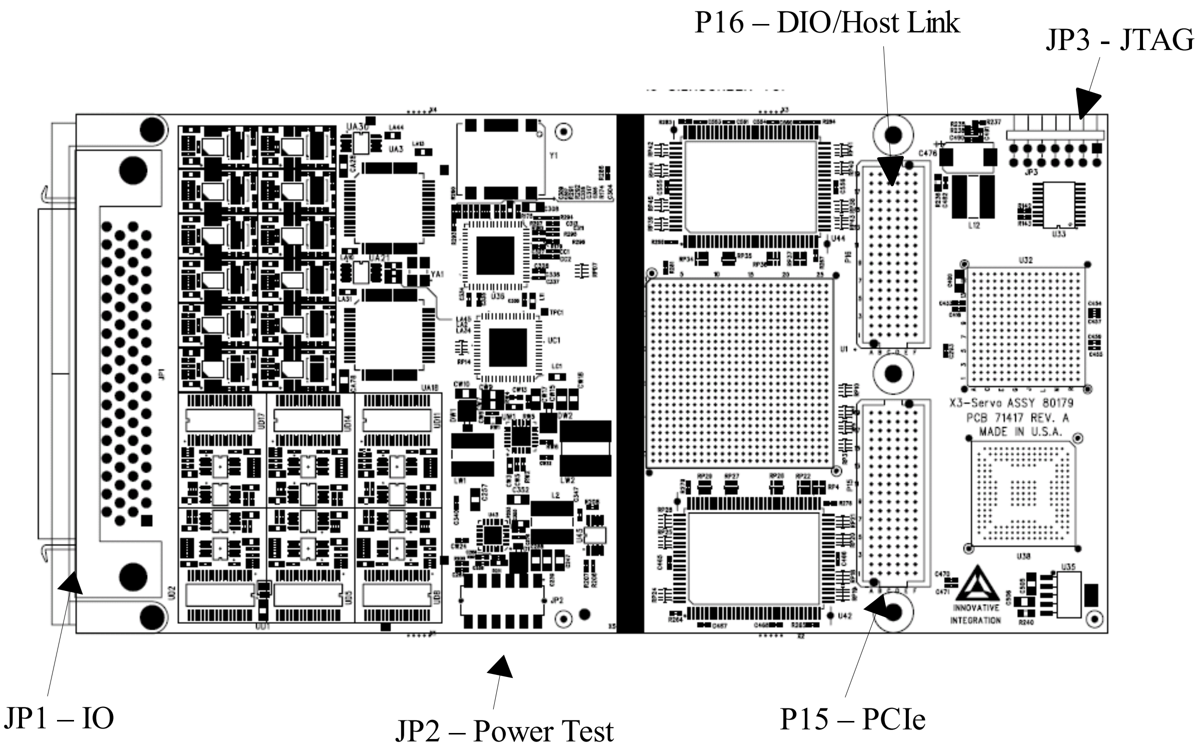


Figure 19. X3-Servo Mechanicals (Bottom View) Rev B

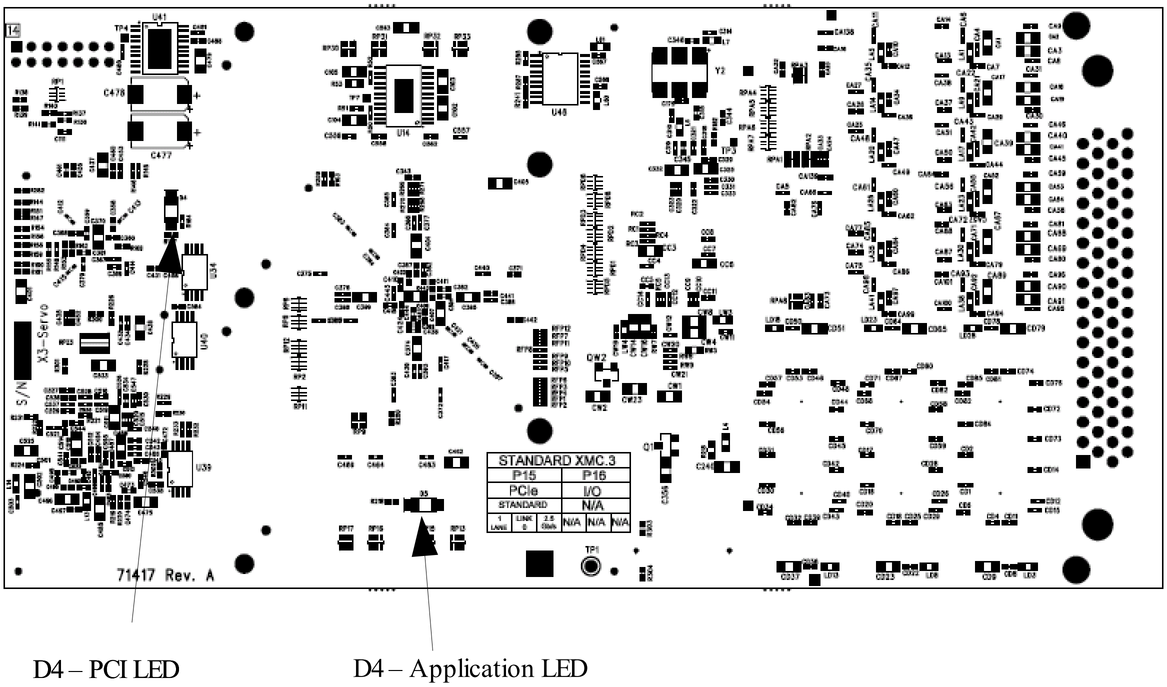


Figure 20. X3-Servo Mechanicals (Top View) Rev B